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Technical
Information for
Problem
Spills

SODIUM SULPHATE

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ENVIRONMENTAL AND TECHNICAL INFORMATION FOR PROBLEM SPILLS MANUALS

The Environmental and Technical Information for Problem Spills (EnviroTIPS) manuals provide detailed information on chemical substances. This information is intended to assist the reader in designing countermeasures for spills and to assess their impact on the environment. The report has been reviewed by the Technical Services Branch, Environmental Protection Service, and approved for publication. Approval does not signify that the contents reflect the views and policies of the Environmental Protection Service. Mention of trade names or commercial products does not constitute endorsement for use.

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SODIUM SULPHATE

ENVIRONMENTAL AND TECHNICAL INFORMATION FOR PROBLEM SPILLS

Technical Services Branch
Environmental Protection Programs Directorate
Environmental Protection Service
Ottawa, Ontario

June 1985

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FOREWORD

The Environmental and Technical Information for Problem Spills (EnviroTIPS) manuals were initiated in 1981 to provide comprehensive information on chemicals that are spilled frequently in Canada. The manuals are intended to be used by spill specialists for designing countermeasures for spills and to assess their effects on the environment. The major focus of EnviroTIPS manuals is environmental. The manuals are not intended to be used by first-response personnel because of the length and technical content; a number of manuals intended for first-response use are available. The information presented in this manual was largely obtained from literature review. Efforts were made, both in compilation and in review, to ensure that the information is as correct as possible. Publication of these data does not signify that they are recommended by the Government of Canada, nor by any other group.

ACKNOWLEDGEMENTS

The final version of this manual was prepared by the staff of the Environmental Protection Service who wrote extensive revisions to the text, drafted illustrations and incorporated all comments and additions.

The level of detail present was made possible by the many individuals, organizations and associations who provided technical data and comments throughout the compilation and subsequent review of and input to this manual. The draft of this manual was prepared under contract to Environment Canada by M.M. Dillon Consulting Engineers and Planners, Concord Scientific Corporation and Waterloo Engineering Limited.

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1 SUMMARY

SODIUM SULPHATE (Na_2SO_4)

White to grey or tan powder or pellets, with no odour.

SYNONYMS

Disodium Sulphate, Salt Cake, Anhydrous Sodium Sulphate, Sulphuric Acid Disodium Salt, Thenardite, Miralolite, Glauber's Salt ($NA_2SO_4 \cdot 10H_2O$)

IDENTIFICATION NUMBERS

UN. No. Not regulated; CAS No. 7757-82-6; OHM-TADS No. 7216904; STCC No. Not required.

GRADES & PURITIES

Natural salt cake, 90 percent or greater

Detergent or rayon grade, >98 percent

Technical, calcined grade, 94 to 96 percent

IMMEDIATE CONCERNS

Fire: Not combustible.

Human Health: Low toxicity.

Environment: Harmful to aquatic life, animals and plants in high concentrations.

PHYSICAL PROPERTY DATA

State (15°C, 1 atm): solid
Melting Point: 884°C
Flammability: noncombustible
Specific gravity: 2.68 (20°/4°C)
Solubility (in water): 4.76 g/100 mL (0°C)
Behaviour (in water): sinks and mixes; no reaction
Odour Threshold: odourless

ENVIRONMENTAL

Sodium sulphate is toxic to aquatic life in high concentrations, generally over 1000 mg/L. Concentrations of 7000 mg/L and over were found to be harmful to domestic animals. Concentrations of 4000 mg/L in solid are injurious to plants, depressing root growth and water absorption. Sodium sulphate does not show bioaccumulation or food chain contamination potential.

HUMAN HEALTH

No TLV® or IDLH established.

Exposure Effects

Contact: Irritation and watering of eyes.

IMMEDIATE ACTION

Spill Control

Restrict access to spill site. Notify manufacturer. Stop the flow and contain spill, if safe to do so. Keep contaminated water from entering sewers or watercourses.

Fire Control

Use fire extinguishing agents appropriate for materials actually burning.

COUNTERMEASURES

Emergency Control Procedures in/on

Soil: Construct barriers to contain spill. Remove material by manual or mechanical means.

Water: Contain by damming, water diversion or natural barriers.

2 PHYSICAL AND CHEMICAL DATA

Physical State Properties	
Appearance	Dark grey pellets (technical calcined) and light tan powder (technical anhydrous) (Koppers PD 1981)
Usual shipping state	Solid
Physical state at 15°C, 1 atm	Solid
Melting point	884°C (CRC 1980)
Densities	
Density	2.69 g/cm^3 (20°C) (Ullmann 1975)
Specific gravity	2.68 (20°/4°C) (CRC 1980)
Fire Properties	
Flammability	Noncombustible (CCD 1977)
Other Properties	
Molecular weight of pure substance	142.04 (CRC 1980)
Constituent components of typical commercial grade	Calcined: 94 to 96 percent anhydrous sodium sulphate, 3 to 5 percent sodium carbonate Anhydrous: 98 percent min. Na_2SO_4, 0.5 percent max. Na_2SO_3 (Koppers PD 1981)
Refractive index	1.464 (rhombic) 1.474 (monoclinic) 1.485 (hexagonal) (Kirk-Othmer 1983)
Viscosity	2.48 (22 percent solution, 20°C) (CRC 1980)
Latent heat of fusion	24.4 kJ/mole (at melting point) (CRC 1980)
Heat of formation	-1387 kJ/mole (JANAF 1971)
Entropy	149.6 J/(mole·K) (Ullmann 1975)
Heat of solution	1.17 kJ/mole (18°C) (Perry 1973)
Heat capacity constant pressure (C_p)	127.8 J/(mole·°C) (JANAF 1971)
Coefficient of thermal expansion	0.410 x 10^{-3}/°C (24 percent solution, 20°C) (Lange's Handbook 1979)

Thermal conductivity	0.605 W/(m-K) (10 percent solution, 32°C) (Lange's Handbook 1979)
Dielectric constant	7.8 (Ullmann 1975)
Eutectic compositions	12.7 percent aqueous solution (f.p. -3.55°C) (Lange's Handbook 1979)

Solubility

In water	4.76 g/100 mL (0°C) (CRC 1980)
In other common materials	Soluble in hydrogen iodide and glycerin; insoluble in ethanol (CRC 1980)

The solubility in various solvents is given below (Ullmann 1975):

Solvent	Sodium Sulphate Solubility (percent)	Temperature (°C)
Methanol	0.025	20
Ethanol	0.002	20
Ethylene glycol	0.54	25
40 percent ammonia in water	1.3	23

Properties of Glauber's Salt

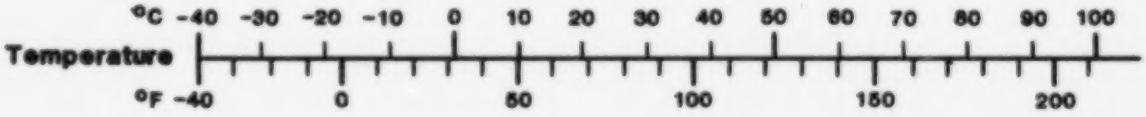
The decahydrate ($Na_2SO_4 \cdot 10H_2O$), or Glauber's salt, is occasionally encountered. Its properties are given below:

Melting point	32.4°C (looses water) (Kirk-Othmer 1983)
Density	1.468 g/cm^3 (20°C) (Ullmann 1975)
Molecular weight	322.19 (Ullmann 1975)
Water content	55.9 percent (Ullmann 1975)
Refractive index	1.394 to 1.398 (Ullmann 1975)
Heat of formation	-4327 kJ/mole (Ullmann 1975)
Heat of solution	-78.5 kJ/mole (Ullmann 1975)
Heat capacity (C_p)	588.2 J/(mole-K) (27°C) (Ullmann 1975)

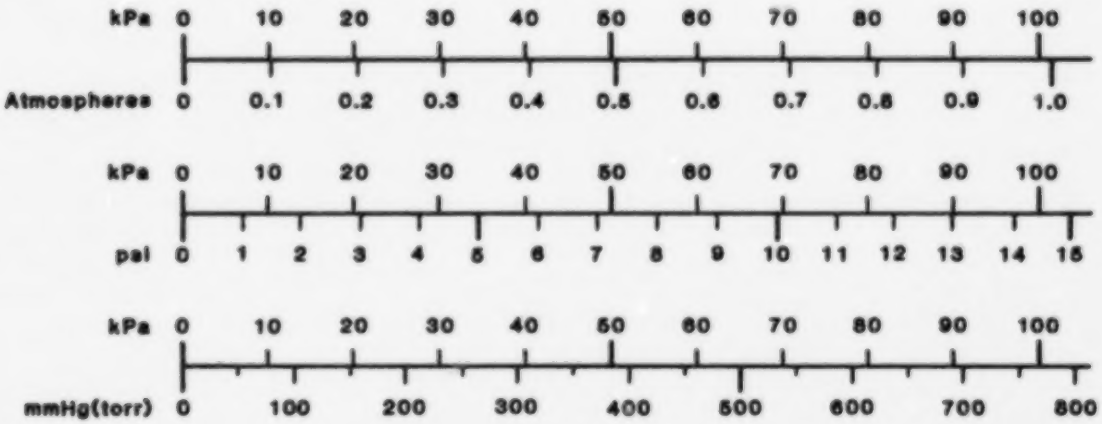
TABLE 1

SODIUM SULPHATE

CONVERSION NOMOGRAMS



Pressure 1 kPa = 1 000 Pa



Viscosity

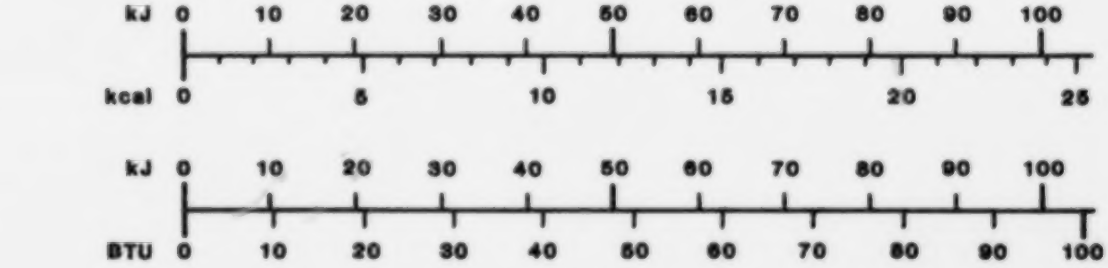
Dynamic 1 Pa-s = 1 000 centipoise (cP)

Kinematic 1 m^2/s = 1 000 000 centistokes (cSt)

Concentration (in water)

1 ppm ≅ 1 mg/L

Energy (heat) 1 kJ = 1 000 J



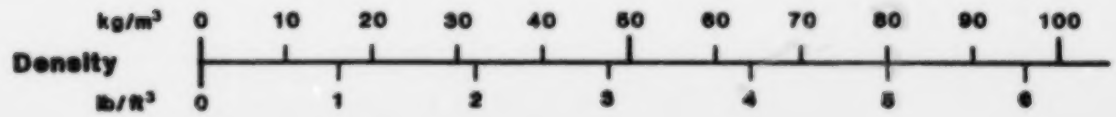
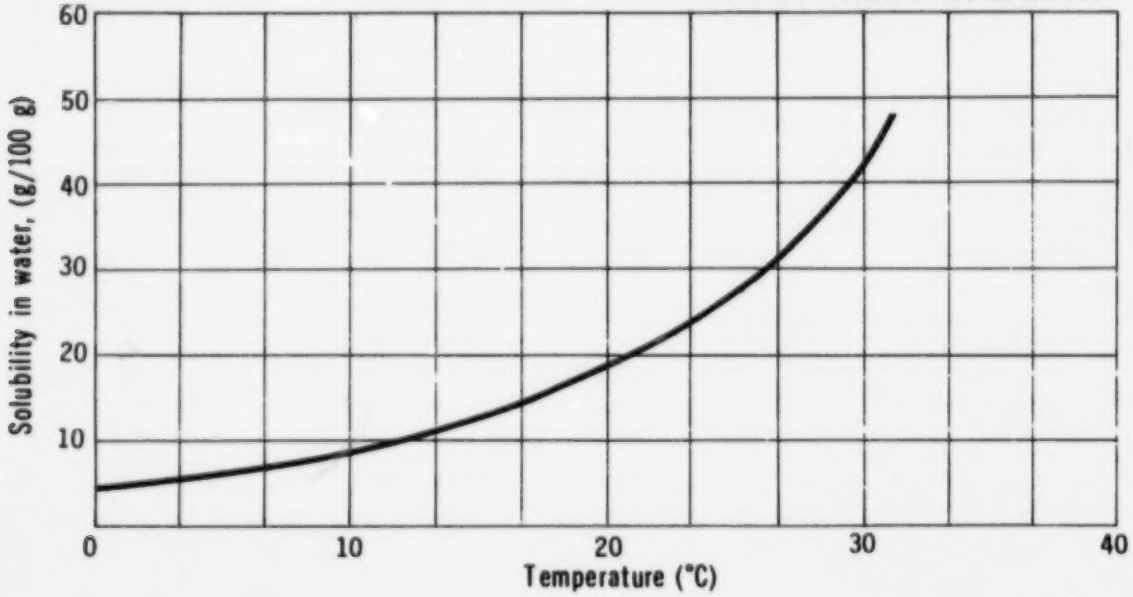


FIGURE 1

SODIUM SULPHATE

SOLUBILITY IN WATER VS TEMPERATURE

Reference: SEIDELL and LINKE 1965



3 COMMERCE AND PRODUCTION

3.1 Grades, Purities (Corpus 1984; Koppers PD 1981; MCP 1979)

Sodium sulphate is produced in natural salt cake form, (purity, >90 percent), and in detergent and rayon (purity, >98 percent; NaCl, <2 percent; iron, 60 percent ppm), glassmakers (purity, >99 percent; low in metals and iron), technical calcined (purity, >94 percent), and U.S.P. (purity, >99 percent) grades.

3.2 Domestic Manufacturers (Corpus 1984; CBG 1980)

These are corporate headquarters' addresses and are not intended as spill response contacts:

Alberta Sulphate Ltd.
407-9900 Jasper Avenue
Edmonton, Alberta
T5J 1P6
(403) 426-6610

Courtaulds (Canada) Ltd.
1150 Montreal Road
Cornwall, Ontario
K6H 5S2
(613) 933-1180

Francana Minerals Ltd.
670 Bank of Canada Bldg.
Regina, Saskatchewan
S4P 0M8
(306) 352-5657

Hudson Bay Mining and Smelting Co. Ltd.
P.O. Box 28
Toronto-Dominion Centre
Toronto, Ontario
M5K 1B8
(416) 362-2192

Midwest Chemicals Ltd.
P.O. Box 66
Edmonton, Alberta
(403) 426-1760

Noranda Sales Corp. Ltd.
P.O. Box 45, Commerce Court West
Toronto, Ontario
M5L 1B6
(416) 867-7111

Ontario Paper Co. Ltd.
80 King Street, Box 3026
St. Catherines, Ontario
L2R 7G2
(416) 688-5030

Ormiston Mining and Smelting Co. Ltd.
502 Scott Bldg.
Moose Jaw, Saskatchewan
S6H 0B9
(306) 692-9611

Saskatchewan Minerals
P.O. Box 120
Chaplin, Saskatchewan
S0H 0V0
(306) 395-2561

3.3 Other Suppliers (CBG 1980)

Arliss Chemical Co. Inc.
325 Hymus Blvd.
Pointe-Claire, Quebec
H9R 1G8
(514) 694-2170

Canada Chrome & Chemicals Ltd.
5468 Dundas Street West
Toronto, Ontario
M9B 6E3
(416) 239-8922

Canada Colours and Chemicals Ltd.
80 Scarsdale Road
Don Mills, Ontario
M3B 2R7
(416) 924-6831

C-I-L Inc.
90 Sheppard Avenue East
North York, Ontario
M2N 5S8
(416) 226-7532 or 226-7250

Coté Chemicals Inc.
111 Bombardier Park
Chateauguay Centre, Quebec
J6J 3X0
(514) 691-6260

International Chemical Canada Ltd.
P.O. Box 385
Brampton, Ontario
L6V 2L3
(416) 453-4234

Lawrason's Chemicals Ltd.
180 Adelaide Street South, Box 2425
London, Ontario
N6A 4G3
(519) 686-9335

3.4 Major Transportation Routes

Current Canadian production of sodium sulphate is located primarily in Saskatchewan, at Palo, Grant, Chaplin, Fox Valley, Hardene, Ormiston, Bishopric and Gladmar (78 percent of total production). Other production facilities are located in Alberta and Ontario. The product is shipped to all provinces for use in wood pulping.

3.5 Production Levels (Corpus 1984)

Company, Plant Location	Nameplate Capacity kilotonnes/yr (1983)
Alberta Sulphate, Metiskow, Alta.	90
Courtaulds Canada, Cornwall, Ont.*	20
Francana Minerals, Grant, Sask.	90
Francana Minerals, Hardene, Sask.	45
Midwest Chemicals, Palo, Sask.	109
Ontario Paper, Thorold, Ont.*	77
Ormiston Mining & Smelting, Ormiston, Sask.	90
Saskatchewan Minerals, Bishopric, Sask.	3
Saskatchewan Minerals, Chaplin, Sask.	135
Saskatchewan Minerals, Fox Valley, Sask.	135
Saskatchewan Minerals, Gladmar, Sask.	19
TOTAL	813

Company, Plant Location	Nameplate Capacity kilotonnes/yr (1983)
Domestic Productions (1983)	534.5
Imports (1983)	22.5
TOTAL SUPPLY	557.0

* by-product operation

3.6 Future Development (CCP 1982)

The British Columbia Ministry of Energy, Mines and Resources has received a proposal for a potassium sulphate/sodium sulphate plant to be built by Canterra Energy, Entreprise Minière et Chimique Sumitomo, with start-up scheduled for 1986.

3.7 Manufacture of Sodium Sulphate (Broughton 1974; FKC 1975)

3.7.1 General. Crude Glauber's salt is purified by recrystallization and heated to produce anhydrous sodium sulphate.

3.7.2 Process. Crude Glauber's salt is either mined from surface deposits and dissolved in water, or solution-mined. Insoluble impurities are settled and filtered out of the "brine" solution; the brine is then evaporated and chilled to produce a slurry of Glauber's salt crystals. The crystals are filtered from the mother liquor, which is returned to the process, then they are melted in an evaporator and dried in a rotary kiln.

3.8 Major Uses in Canada (Corpus 1984)

Sodium sulphate is used primarily in wood pulping. It is also used in detergents, glass making, textile mordant, animal feeds, and solar trays.

3.9 Major Buyers in Canada (Corpus 1984)

Abitibi-Price, Smooth Rock Falls, Ont.
Abitibi-Price, Jonquière, Que.
B.C. Forest Products, Crofton, MacKenzie, B.C.
Boise Cascade, Ft. Frances, Ont.
Boise Cascade, Miramichi, N.B.
Canadian Cellulose, Prince Rupert, B.C.
Canadian Forest Products, Port Mellon, B.C.
Canadian International Paper, La Tuque, Que.
Cariboo Pulp, Quesnel, B.C.

Colgate-Palmolive, Toronto, Ont.
Consolidated-Bathurst, Bathurst, N.B.
Consumers Glass, Toronto, Ont.
Crestbrook Forest Industries, Skookumchuk, B.C.
Crown Zellerbach, Campbell R., B.C.
Domglas, Hamilton, Ont.
Domtar, Windsor, Ont.
Eddy Forest Products, Espanola, Ont.
Eurocan Pulp, Kitimat, B.C.
Great Lakes Forest Products, Dryden, Ont.
Intercontinental Pulp, Prince George, B.C.
Irving Pulp, Saint John, N.B.
Kimberly-Clark, Terrace Bay, Ont.
Lever Detergents, Toronto, Ont.
MacMillan Bloedel, Nanaimo, B.C.
Manitoba Forestry Resources, Le Pas, Man.
Northwood Pulp, Prince George, B.C.
Prince Albert Pulp, Prince Albert, Sask.
Prince George Pulp, Prince George, B.C.
Proctor & Gamble, Hamilton, Ont.
St. Regis, Hinton, Alta.
Scott Maritime, Abercrombie, N.S.
Tahsis, Gold River, B.C.
Thurso Pulp & Paper, Thurso, Que.
Western Forest Products, Squamish, B.C.
Weyerhaeuser, Kamloops, B.C.
Witco Chemical Canada, Oakville, Ont.

4 MATERIAL HANDLING AND COMPATIBILITY

4.1 Containers and Transportation Vessels

4.1.1 General. Sodium sulphate solid is shipped primarily in bulk by rail or truck, or in drums and boxes.

4.1.1.1 Railway hopper cars. Railway hopper cars used to transport sodium sulphate are illustrated in Figure 2. Table 2 provides typical details.

4.1.1.2 Truck transport. Sodium sulphate solid is also shipped in trucks.

4.1.2 Packaging. In addition to bulk shipments, sodium sulphate solid is also transported in drums and boxes. Drums fabricated from a variety of construction materials are permitted. Table 3 lists drum types and descriptions (TDGC 1980). Metal, wooden or fiberboard boxes with inner containers fabricated from glass, metal, plastic or earthenware may also be used. Maximum net capacity of the box and the individual inside packagings is 23 and 11 kg (51 and 24 lb), respectively (HMR 1978).

4.2 Compatibility with Materials of Construction

The compatibility of sodium sulphate with materials of construction is indicated in Table 4. The unbracketed abbreviations are described in Table 5. The rating system for this report is briefly described below.

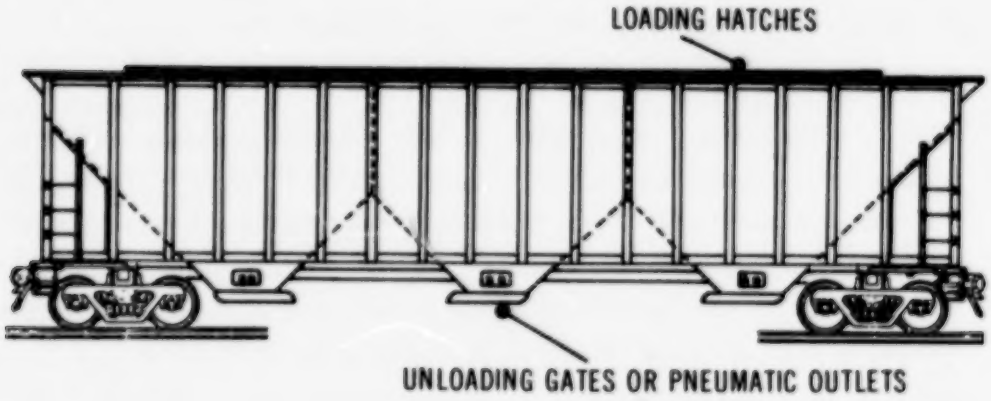
Recommended:	These materials will perform satisfactorily in the given application.
Conditional:	Material will show deterioration in the given application; however, it may be suitable for intermittent or short-term service.
Not Recommended:	Material will be severely affected in this application and should not be used.

FIGURE 2

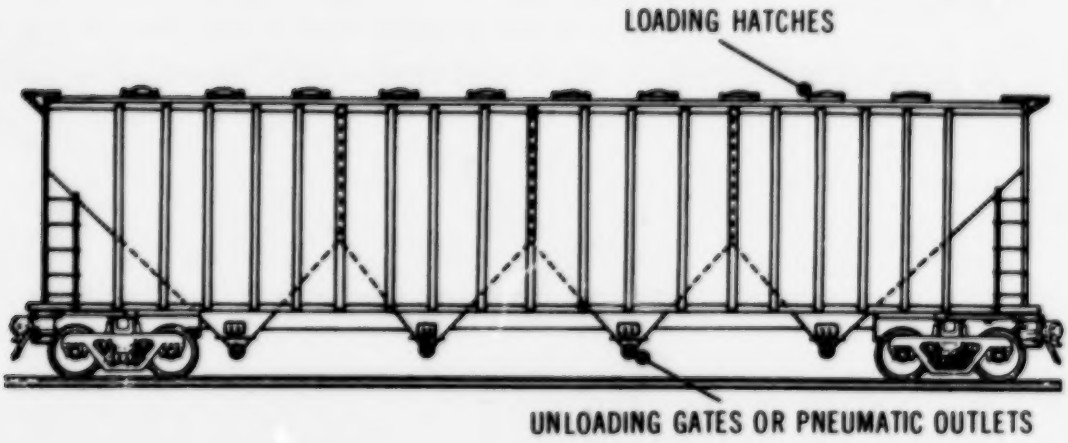
SODIUM SULPHATE

COVERED HOPPER CARS - AAR CLASS LO

(Reference - CLC 1974, AAR 1983)



Typical 3 - Compartment Hopper Car



Typical 4 - Compartment Hopper Car

TABLE 2 TYPICAL RAILWAY HOPPER CAR SPECIFICATIONS - AAR CLASS LO (CLC 1974)

Description	Hopper Car Size (cu. ft.) 5800	4700
Overall		
Nominal capacity	164 m^3 (5800 cu. ft.)	133 m^3 (4700 cu. ft.)
Weight capacity	86 000 kg (190 000 lb.)	89 000 kg (196 000 lb.)
Car weight - empty	45 000 kg (100 000 lb.)	45 000 kg (100 000 lb.)
Car weight - max.	119 000 kg (263 000 lb.)	119 000 kg (263 000 lb.)
Hoppers/Compartments		
Number	4	3
Material	steel	
Inside length (typical)	410 cm (160 in.)	460 cm (180 in.)
Inside width (typical)	300 cm (118 in.)	300 cm (118 in.)
Spacing between outlets	4 m (13 ft.)	5 m (15 ft.)
Slope angle	40 to 45°	40 to 45°
Approximate Dimensions		
Coupled length	21 m (68 ft.)	18 m (60 ft.)
Length over strikers	20 m (65 ft.)	17 m (57 ft.)
Length of truck centres	16 m (54 ft.)	14 m (46 ft.)
Clearance height	5 m (15 ft.)	5 m (15 ft.)
Height to top of running board	5 m (15 ft.)	4 m (14 ft.)
Overall width	3.1 m (123 in.)	3.2 m (126 in.)
Inside length	19 m (63 ft.)	17 m (55 ft.)
Loading/Unloading Fixtures		
Loading Hatches:	Cars typically equipped with 4 to 12 loading hatches. Typical dimensions of these are 36 to 61 cm (14 to 24 in.) in diameter or square dimensions.	
Unloading Fixtures:	Equipped with unloading gates at bottom of 36 to 61 cm (14 to 24 in.) square and/or pneumatic unloading connections 10 to 20 cm (4 to 8 in.) in diameter.	

TABLE 3 DRUMS

Type of Drum	Designation	Description	Figure No. (If Any)
Steel	1A1	Nonremovable head, reusable	3
	1A1A	1A1 with reinforced chime	3
	1A1B	1A1 with welded closure flange	3
	1A1C	1A1 with lead coating	3
	1A1D	1A1 with coating (other than lead)	3
	1A2	Removable head, reusable	3
	1A2A	1A2 with reinforced chime	3
	1A2B	1A2 with lead coating	3
	1A3	Nonremovable head, single use only	3
	1A4	Removable head, single use only	3
Plywood	1D2		
Fibreboard	1G1	Convolutely wound plies. Maximum capacity 250 L (55 gal.) Maximum net mass 400 kg (882 lb.)	
Plastic	1H1	Nonremovable head. Maximum capacity 250 L (55 gal.) Maximum net mass 400 kg (882 lb.)	
	1H2	Same as 1H1 except head removable	
Steel Drums with inner plastic receptacles	6HA1	Outer steel sheet in the shape of drum. Inner plastic receptacle. Maximum capacity 225 L (49 gal.)	
Plywood Drums with inner plastic receptacles	6HD1	Outer plywood in shape of drum. Inner plastic receptacle. Maximum capacity 225 L (49 gal.)	
Fibreboard Drums with inside plastic receptacles	6HG1	Outer containers of convolutely wound plies of fibreboard. Inner plastic in shape of drum. Maximum capacity 225 L (49 gal.)	

* See Section 4.2 of this report.

FIGURE 3

SODIUM SULPHATE

TYPICAL DRUM CONTAINER

Typical steel drum

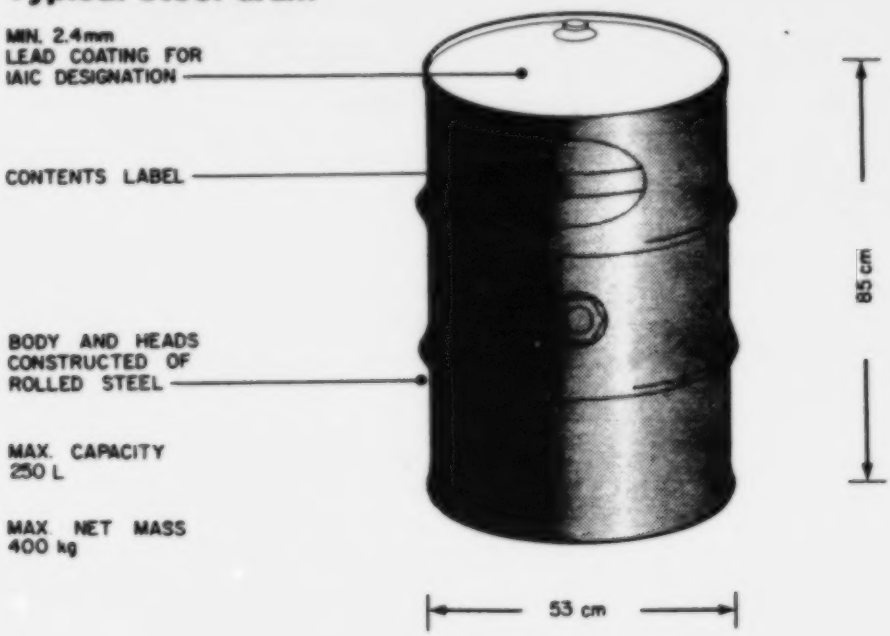


TABLE 4 COMPATIBILITY WITH MATERIALS OF CONSTRUCTION

Application	Chemical		Material of Construction		
	Conc.	Temp. (°C)	Recommended	Conditional	Not Recommended
1. Pipes and Fittings	All	49	PE (DPPED 1967)		
		60	PVC I PVC II (DPPED 1967)		
		71	ABS (DPPED 1967)		
		79	PVDC (DCRG 1978)		
		107	PP (DCRG 1978)		
		121	Chlorinated Polyether (DCRG 1978)		

TABLE 4 COMPATIBILITY WITH MATERIALS OF CONSTRUCTION (Cont'd)

Application	Chemical		Material of Construction		
	Conc.	Temp. (°C)	Recommended	Conditional	Not Recommended
1. Pipes and Fittings (Cont'd)		135	PVDF (DCRG 1978)		
		To operating limit of material	PVC I ABS, PE (MWPP 1978)		
2. Others	Most	Most	CS SS		

TABLE 5 MATERIALS OF CONSTRUCTION

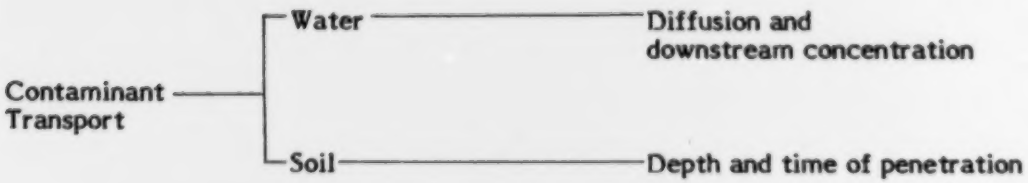
Abbreviation	Material of Construction
ABS	Acrylonitrile Butadiene Styrene
	Aluminum
CS	Carbon Steel
	Chlorinated Polyether
	Glass
	Nickel
	Nickel-Copper Alloy (Monel)
PE	Polyethylene
PP	Polypropylene
PVC (followed by grade, if any)	Polyvinyl Chloride
PVDC	Polyvinylidene Chloride
PVDF	Polyvinylidene Fluoride
SS	Stainless Steel

5 CONTAMINANT TRANSPORT

5.1 General Summary

Sodium sulphate is transported as a solid, in hopper type or pneumatic bulk railway cars. When spilled in water, it will dissolve. Sodium sulphate is essentially nonvolatile, so dispersion in air is not a problem.

Factors considered for the transport of a sodium sulphate spill in water and soil are as follows:



It is important to note that, because of the approximate nature of the contaminant transport calculations, the approach adopted throughout has been to use conservative estimates of critical parameters so that predictions are approaching worst case scenarios for each medium.

5.2 Leak Nomograms

Sodium sulphate is usually transported as a solid; as a result, no leak nomograms have been prepared.

5.3 Dispersion in Air

Sodium sulphate is nonvolatile in foreseeable spill circumstances, so there is no significant potential for dispersion in air. Dusting, which could cause irritation, may be a problem in some spill situations.

5.4 Behaviour in Water

5.4.1 Introduction. When spilled on a water surface, sodium sulphate will sink and dissolve. Mixing takes place and the spill is diluted. This mixing can generally be described by classical diffusion equations with one or more diffusion coefficients. In rivers, the principal mixing agent is stream turbulence while in calm water mixing takes place by molecular diffusion.

To estimate the pollutant concentration in a river downstream from a spill, the turbulent diffusion has been modelled. The one-dimensional model uses an idealized rectangular channel section and assumes a uniform concentration of the pollutant throughout the section. Obviously, this applies only to points sufficiently far downstream of the spill where mixing and dilution have distributed the pollutant across the entire river channel. The model is applicable to rivers where the ratio of width to depth is less than 100 (W/d <100) and assumes a Manning's roughness coefficient of 0.03. Details of the model are outlined in the Introduction Manual.

No modelling has been carried out for molecular diffusion in still water. Rather, nomograms have been prepared to define the hazard zone and the average concentration within the hazard zone as a function of spill size, but independent of time.

5.4.2 Nomograms. The following nomograms are presented to calculate pollutant concentrations in non-tidal rivers and in lakes (still water).

Non-tidal Rivers

Figure 5:	time versus distance for a range of average velocities
Figure 6:	hydraulic radius versus channel width for a range of stream depths
Figure 7:	diffusion coefficient versus hydraulic radius for a range of average stream velocities
Figure 8:	alpha* versus diffusion coefficient for various time intervals
Figure 9:	alpha versus delta* for a range of spill sizes
Figure 10:	maximum concentration versus delta for a range of river cross-sectional areas

Lakes or Still Water Bodies

Figure 11:	volume versus radius for the hazard zone for a range of lake depths
Figure 12:	average concentration versus volume for the hazard zone for a range of spill sizes

The flowchart in Figure 4 outlines the steps required to estimate the downstream concentration after a spill and identifies the nomograms to be used. These nomograms (Figures 5 through 12) are described in the following subsections.

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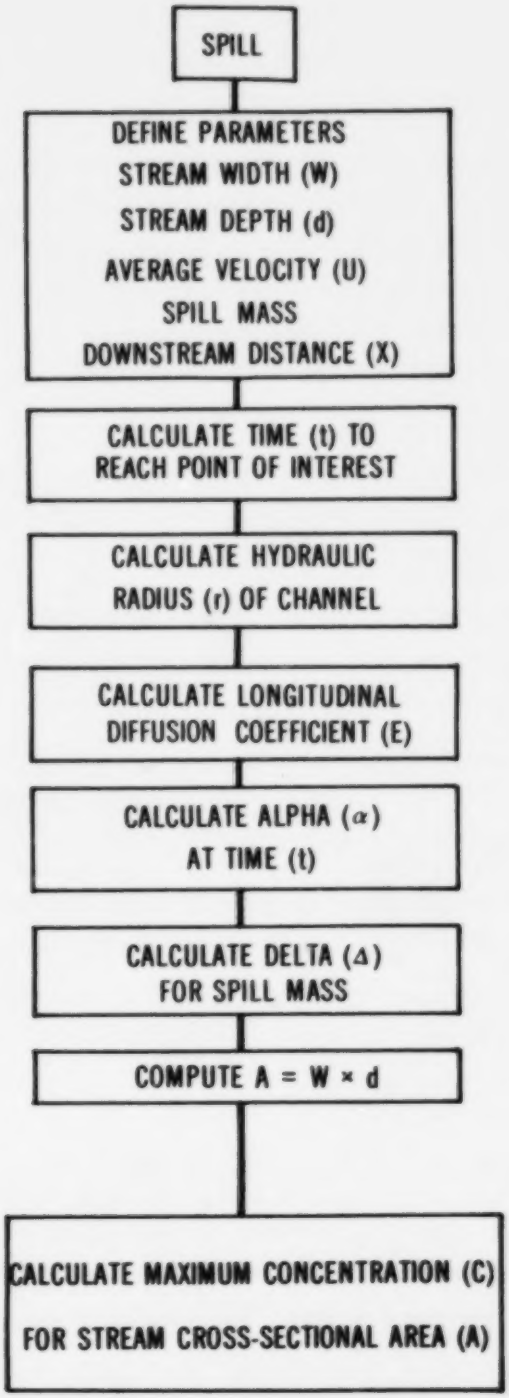
* Alpha and delta are conversion factors only and are of no significance other than to facilitate calculation of downstream concentration.

FIGURE 4

SODIUM SULPHATE

FLOW CHART TO DETERMINE POLLUTANT CONCENTRATION IN NON-TIDAL RIVERS


SPILL
DEFINE PARAMETERS
STREAM WIDTH (W)
STREAM DEPTH (d)
AVERAGE VELOCITY (U)
SPILL MASS
DOWNSTREAM DISTANCE (X)
CALCULATE TIME (t) TO REACH POINT OF INTEREST
CALCULATE HYDRAULIC RADIUS (r) OF CHANNEL
CALCULATE LONGITUDINAL DIFFUSION COEFFICIENT (E)
CALCULATE ALPHA (α) AT TIME (t)
CALCULATE DELTA (Δ) FOR SPILL MASS
COMPUTE A = W × d
CALCULATE MAXIMUM CONCENTRATION (C) FOR STREAM CROSS-SECTIONAL AREA (A)

Step 1: Observed or Estimated

W = _____ m

d = _____ m

U = _____ m/s

MASS = _____ tonnes

X = _____ m

Step 2: Use Figure 9

t = _____ minutes

Step 3: Use Figure 10

r = _____ m

Step 4: Use Figure 11

E = _____ m^2/s

Step 5: Use Figure 12

α = _____

Step 6: Use Figure 13

Δ = _____

Step 7: Compute stream cross-sectional Area (A)

A = W × d _____ m^2

Step 8: Use Figure

C = _____ ppm

5.4.2.1 Nomograms for non-tidal rivers.

Figure 5: Time versus distance. Figure 5 represents a simple relationship between average stream velocity, time, and distance. Using an estimate of average stream velocity (U), the time (t) to reach any point of interest, at some distance (X) downstream of the spill, can be readily obtained from Figure 5.

Figure 6: Hydraulic radius versus channel width. The model used to estimate downstream pollutant concentrations is based on an idealized rectangular channel of width (W) and depth (d). The hydraulic radius (r) for the channel is required in order to estimate the longitudinal diffusion coefficient (E). The hydraulic radius (r) is defined as the stream cross-sectional area (A) divided by the wetted perimeter (P). Figure 6 is a nomogram for computation of the hydraulic radius (r) using the width and depth of the idealized river cross-section.

Figure 7: Diffusion coefficient versus hydraulic radius. Figure 7 permits calculation of the longitudinal diffusion coefficient (E), knowing the hydraulic radius (r) from Figure 6 and the average stream velocity (U).

Figure 8: Alpha versus diffusion coefficient. Figure 8 is used to estimate a conversion factor, alpha (α), which is a function of the diffusion coefficient (E) and the time (t) to reach the point of interest downstream of the spill.

Figure 9: Alpha versus delta. A second conversion factor, delta (Δ), must be estimated from Figure 9 to allow determination of the pollutant concentration at the point of interest. Delta (Δ) is a function of alpha (α) and the spill size.

Figure 10: Maximum concentration versus delta. Figure 10 represents the final step for calculation of the maximum downstream pollutant concentration (C) at the point of interest. Using the factor delta (Δ) and knowing the stream cross-sectional area (A), the concentration (C) is readily obtained from the nomogram. The value obtained from Figure 10 applies to neutrally buoyant liquids or solids and will vary somewhat for other pollutants which are heavier or lighter than water.

5.4.2.2 Nomograms for lakes or still water bodies.

Figure 11: Volume versus radius. The spill of a neutrally buoyant liquid in a lake in the absence of wind and current has been idealized as a cylinder of radius (r) and length (d), equivalent to the depth of the lake at the point of spill. The volume of water

FIGURE 5

SODIUM SULPHATE

TIME vs DISTANCE

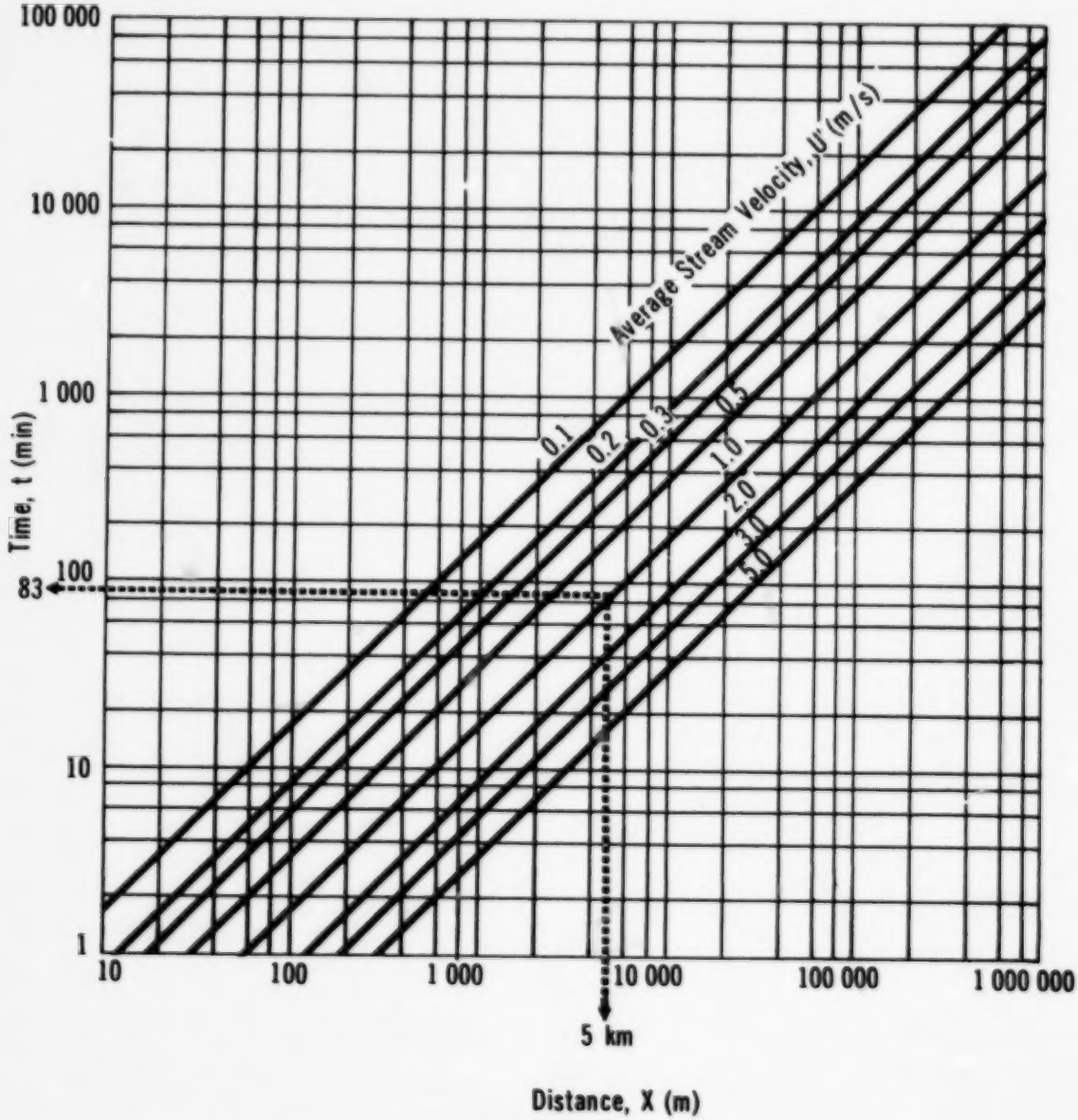


FIGURE 6

SODIUM SULPHATE

HYDRAULIC RADIUS VS CHANNEL WIDTH

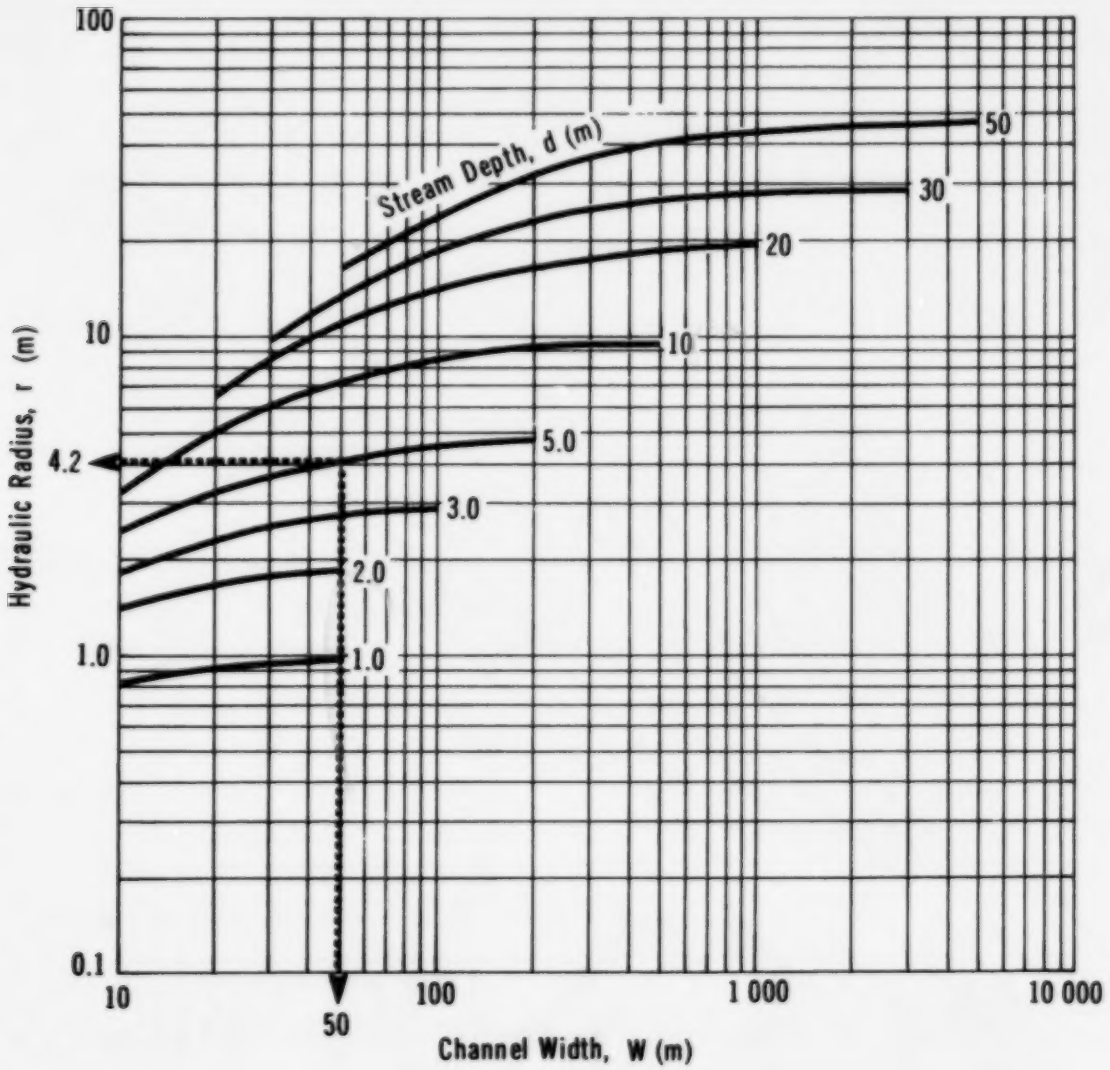


FIGURE 7

SODIUM SULPHATE

DIFFUSION COEFFICIENT
VS HYDRAULIC RADIUS

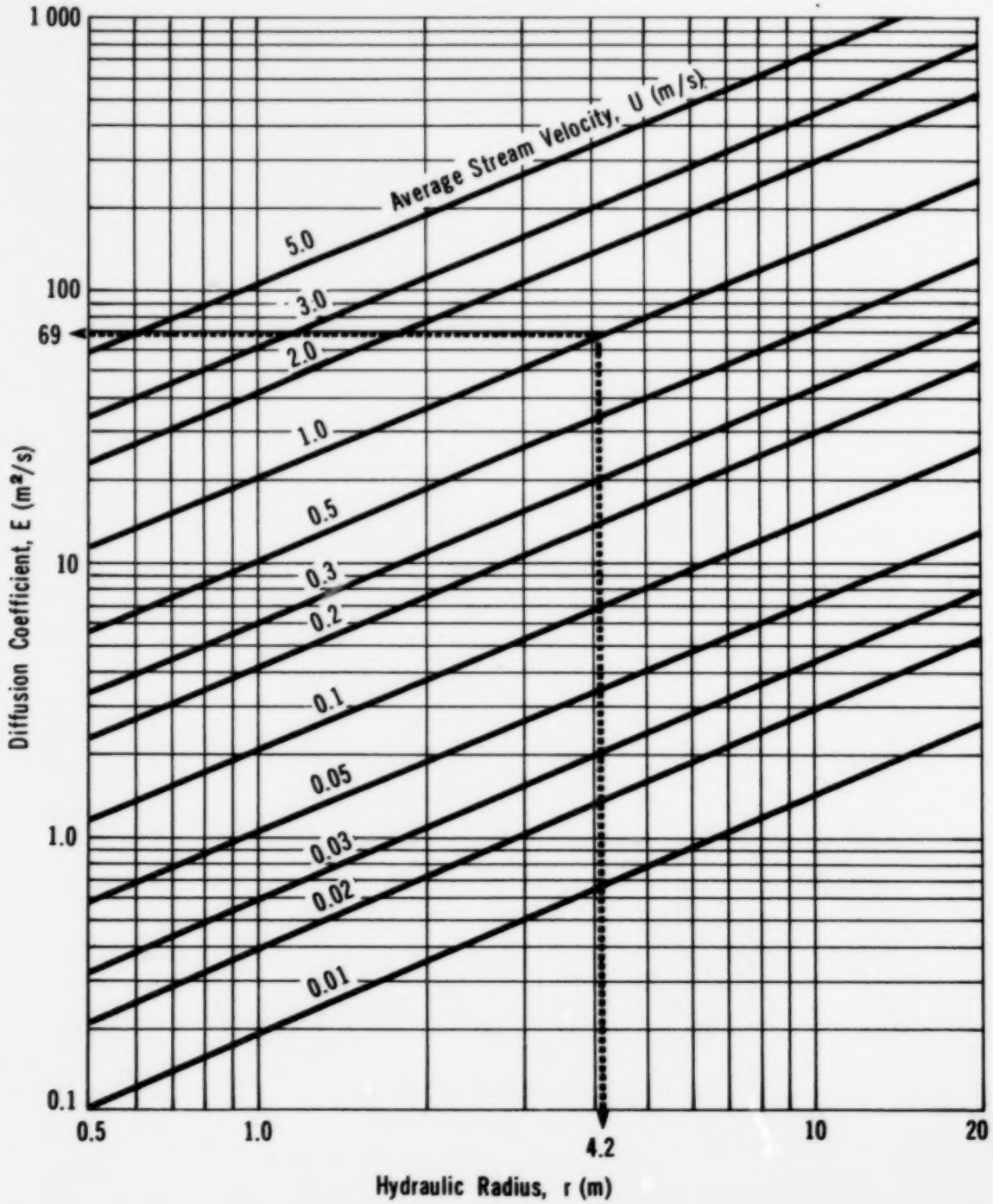


FIGURE 8

SODIUM SULPHATE

ALPHA vs DIFFUSION COEFFICIENT

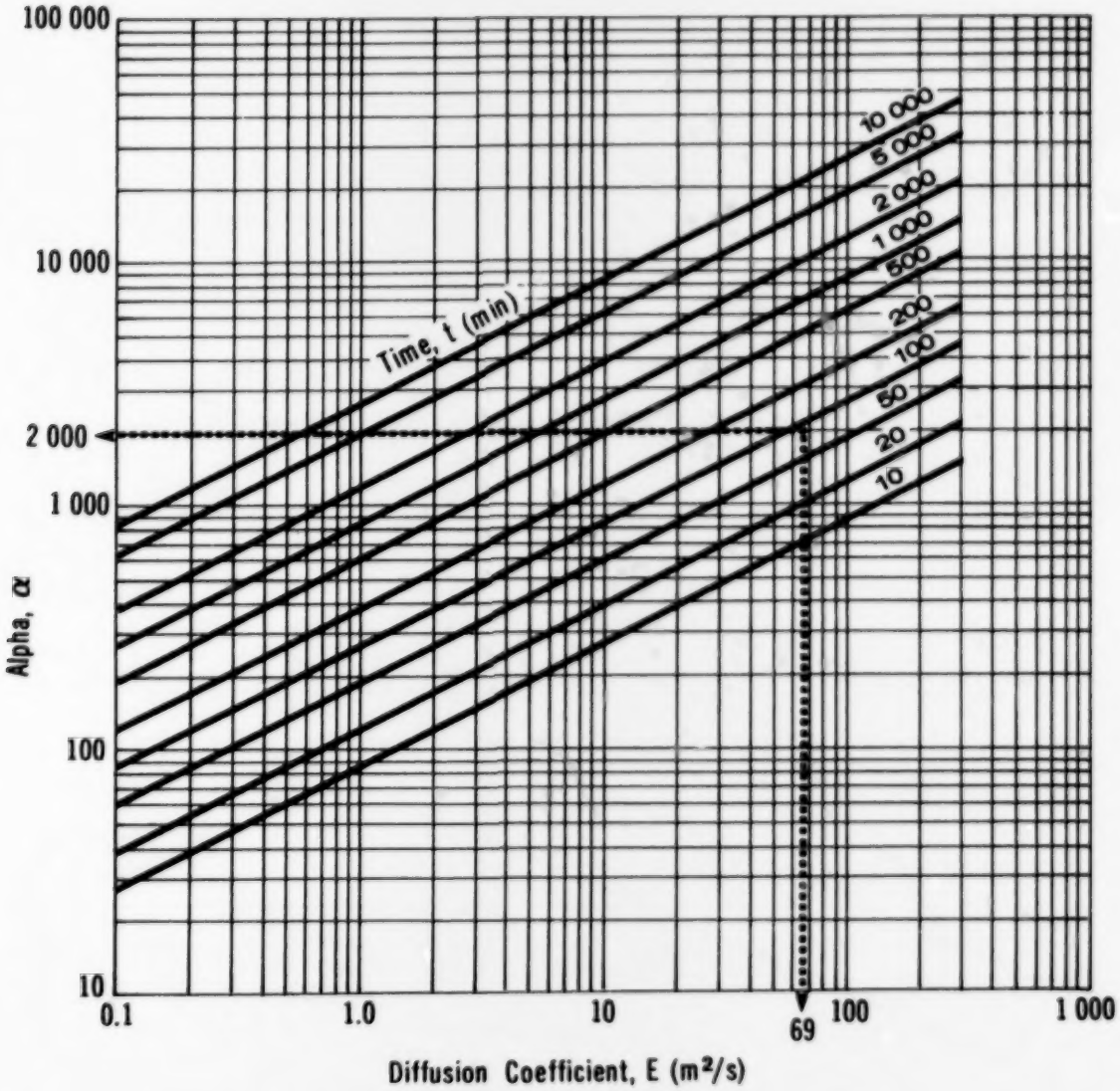


FIGURE 9

SODIUM SULPHATE

ALPHA vs DELTA

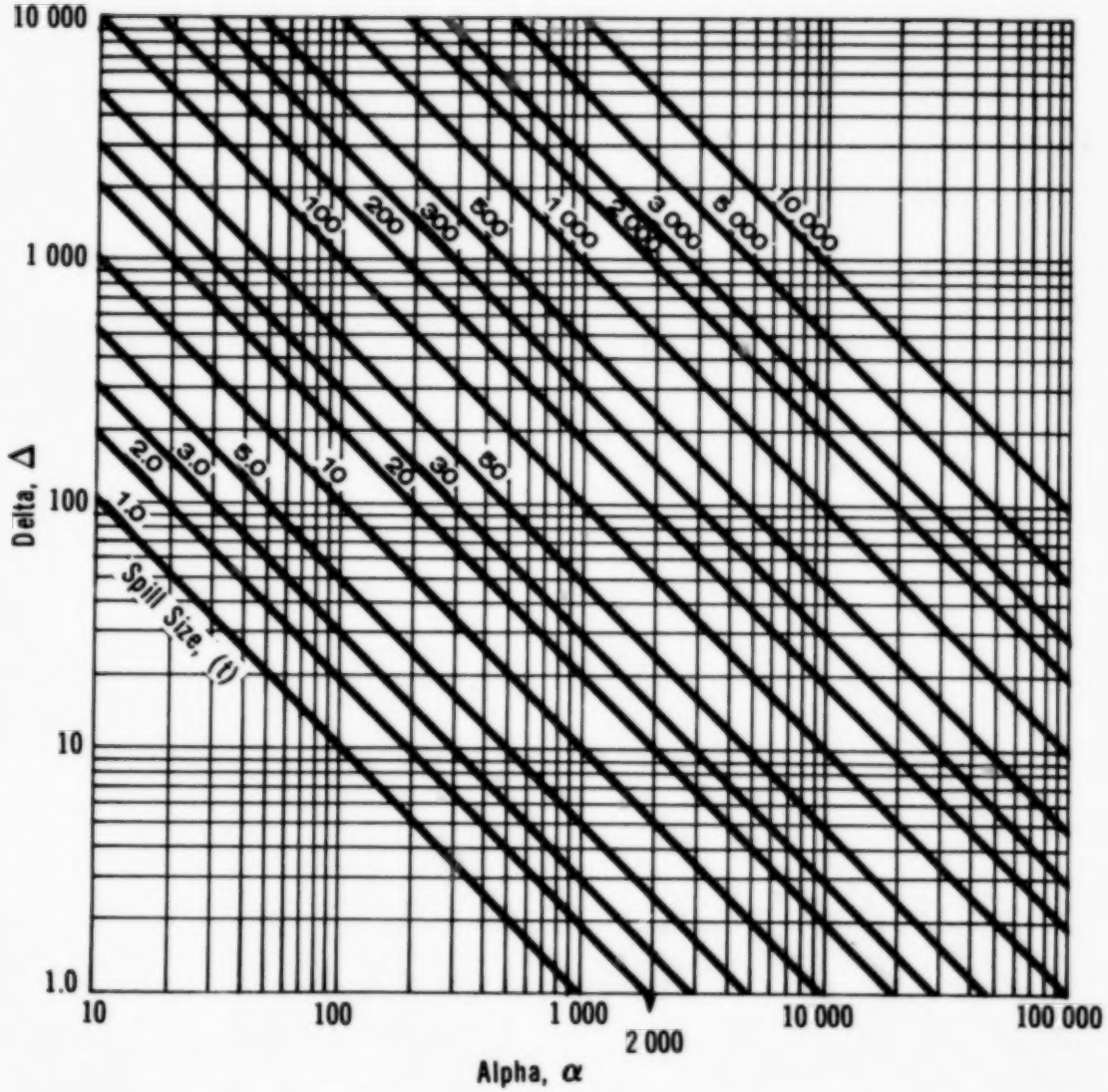


FIGURE 10

SODIUM SULPHATE

MAXIMUM CONCENTRATION vs DELTA

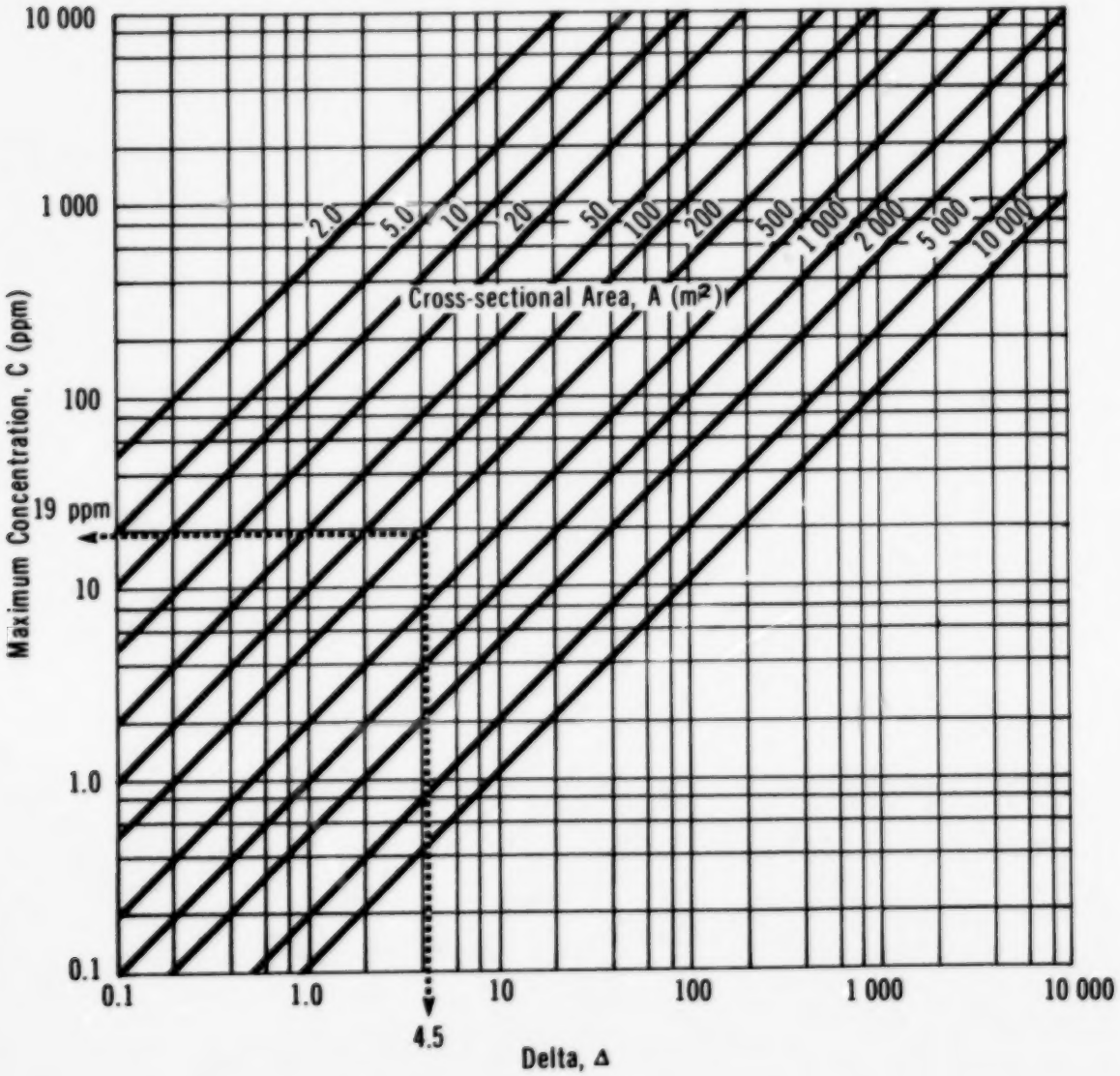
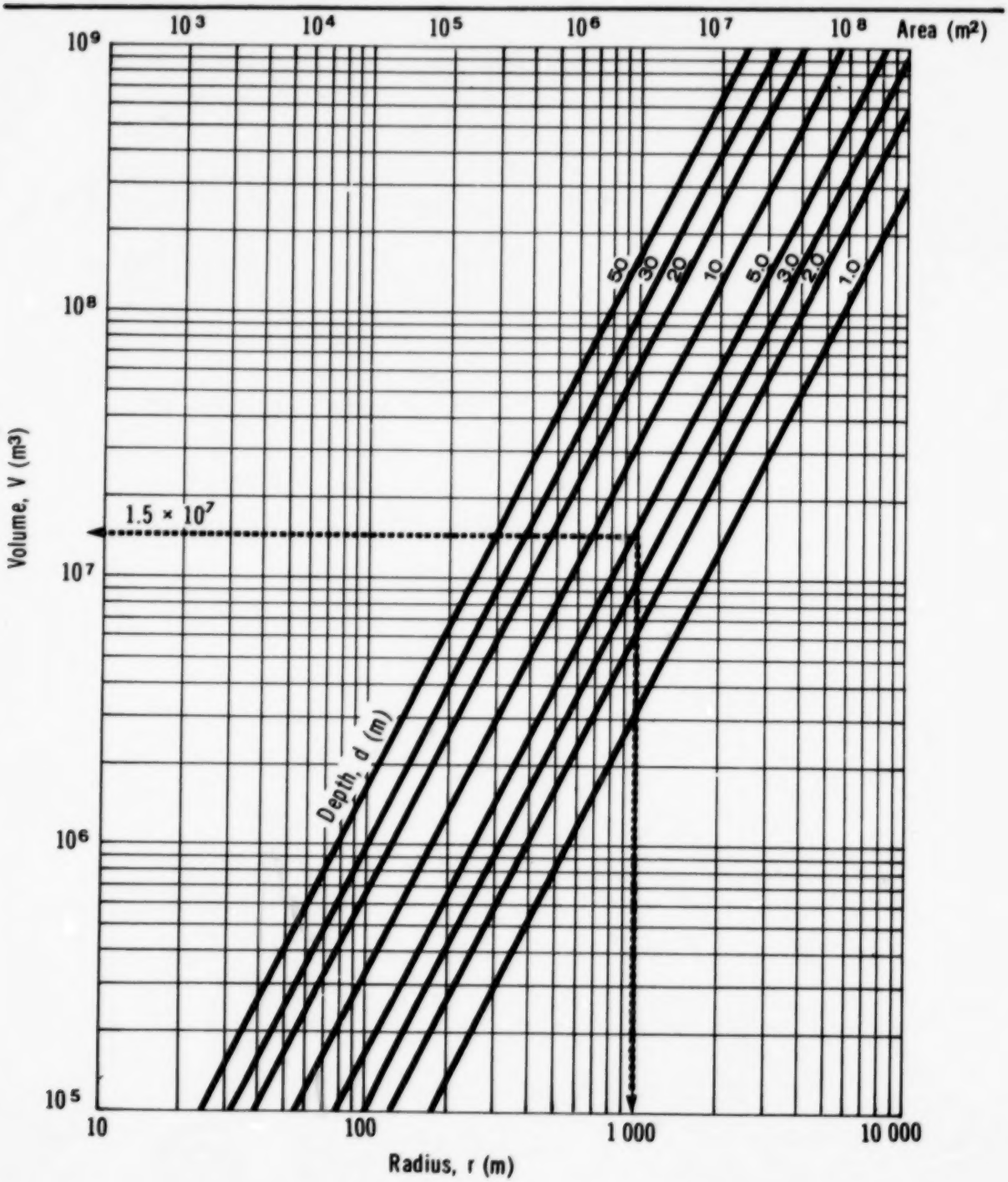


FIGURE 11

SODIUM SULPHATE

VOLUME vs RADIUS



in the cylinder can be obtained from Figure 11. The radius (r) represents the distance from the spill to the point of interest.

Figure 12: Average concentration versus volume. For a known volume of water (within the idealized cylinder of radius (r) and length (d)), the average concentration of pollutant (C) can be obtained from Figure 12 for a known mass of spill. This assumes the pollutant is spread evenly throughout the cylinder. For pollutants that are more or less dense than water, the actual concentration at the bottom would be higher or lower, respectively.

5.4.3 Sample Calculations.

5.4.3.1 Pollutant concentration in non-tidal rivers. A 9-tonne spill of sodium sulphate has occurred in a river. The stream width is 50 m and the stream depth is 5 m. The average stream velocity is estimated at 1 m/s. What is the maximum concentration expected at a water intake located 5 km downstream?

Solution

Step 1: Define parameters

- W = 50 m
- d = 5 m
- U = 1 m/s
- Spill mass = 9 tonnes

Step 2: Calculate the time to reach the point of interest

- Use Figure 5
- With X = 5000 m and U = 1 m/s, t = 83 min

Step 3: Calculate the hydraulic radius (r)

- Use Figure 6
- With W = 50 m and d = 5 m, r = 4.2 m

Step 4: Calculate the longitudinal diffusion coefficient (E)

- Use Figure 7
- With r = 4.2 m and U = 1 m/s, E = 69 m^2/s

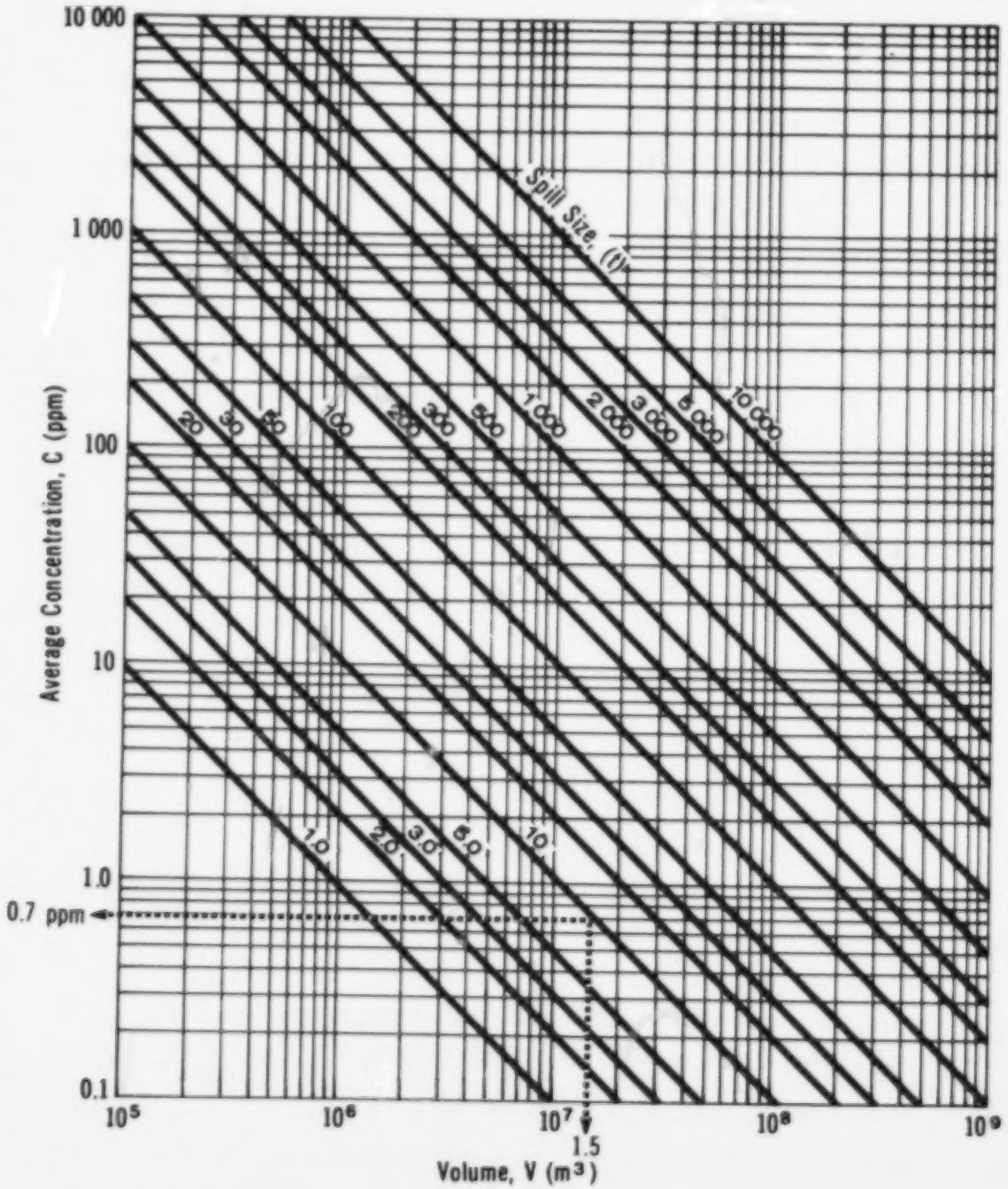
Step 5: Calculate alpha (α)

- Use Figure 8

FIGURE 12

SODIUM SULPHATE

AVERAGE CONCENTRATION vs VOLUME



- With E = 69 m^2/s and t = 83 min, α = 2000

Step 6: Calculate delta (Δ)

- Use Figure 9
- With alpha (α) = 2000 and spill mass = 9 tonnes (sodium sulphate), delta (Δ) = 4.5

Step 7: Compute the stream cross-sectional area (A)

- A = W x d = 50 x 5 = 250 m^2

Step 8: Calculate the maximum concentration (C) at the point of interest

- Use Figure 10
- With Δ = 4.5 and A = 250 m^2, C = 19 ppm

5.4.3.2 Average pollutant concentration in lakes or still water bodies. A 9-tonne spill of sodium sulphate has occurred in a lake. The point of interest is located on the shore approximately 1000 m from the spill. The average depth between the spill site and the point of interest is 5 m. What is the average concentration which could be expected?

Solution

Step 1: Define parameters

- d = 5 m
- r = 1000 m
- Spill mass = 9 tonnes

Step 2: Determine the volume of water available for dilution

- Use Figure 11
- With r = 1000 m, d = 5 m, the volume is approximately 1.5 x 10^7 m^3

Step 3: Determine the average concentration

- Use Figure 12
- With V = 1.5 x 10^7 m^3 and spill mass = 9 tonnes, the average concentration is 0.7 ppm

5.5 Subsurface Behaviour: Penetration into Soil

5.5.1 Mechanisms. Sodium sulphate is conveyed primarily as a solid. When the solid is spilled, only a limited groundwater contamination hazard exists if the soil is dry and if no precipitation or other forms of moisture are present.

Since sodium sulphate is soluble in water, concentrated solutions can infiltrate the soil. Some interaction between sodium sulphate and the soil will occur. However, much of the sodium sulphate exchanged ions will migrate downward through the soil. One study on soil penetration showed that dilute solutions of sodium sulphate penetrated at about the same rate as water. Ionic interaction did not appear to affect this rate (Cairns 1973). If the soil is saturated with moisture at the time of the spill, as might be the case after a rainfall, the spilled chemical may run off with surface water.

For this work, the soils have been assumed to be at field capacity. This situation provides very little interstitial water to dilute the chemical during transport or to impede its downward movement and thus represents "worst case" analysis. Upon reaching the groundwater table, the contaminant will continue to move, now in the direction of groundwater flow. A contaminated plume will be produced, with diffusion and dispersion serving to reduce the concentration somewhat. This is shown schematically in Figure 13.

5.5.2 Equations Describing Dissolved Sodium Sulphate Movement into Soil. The equations and assumptions used to describe contaminant movement in solution downward through the unsaturated soil zone toward the groundwater table have been described in the Introduction Manual. Transport velocities have been based on Darcy's Law assuming saturated piston flow.

5.5.3 Saturated Hydraulic Conductivity of Dissolved Sodium Sulphate in Soil. The saturated hydraulic conductivity (K_o), in m/s, is given by:

$$K_o = \frac{(\rho g)k}{\mu}$$

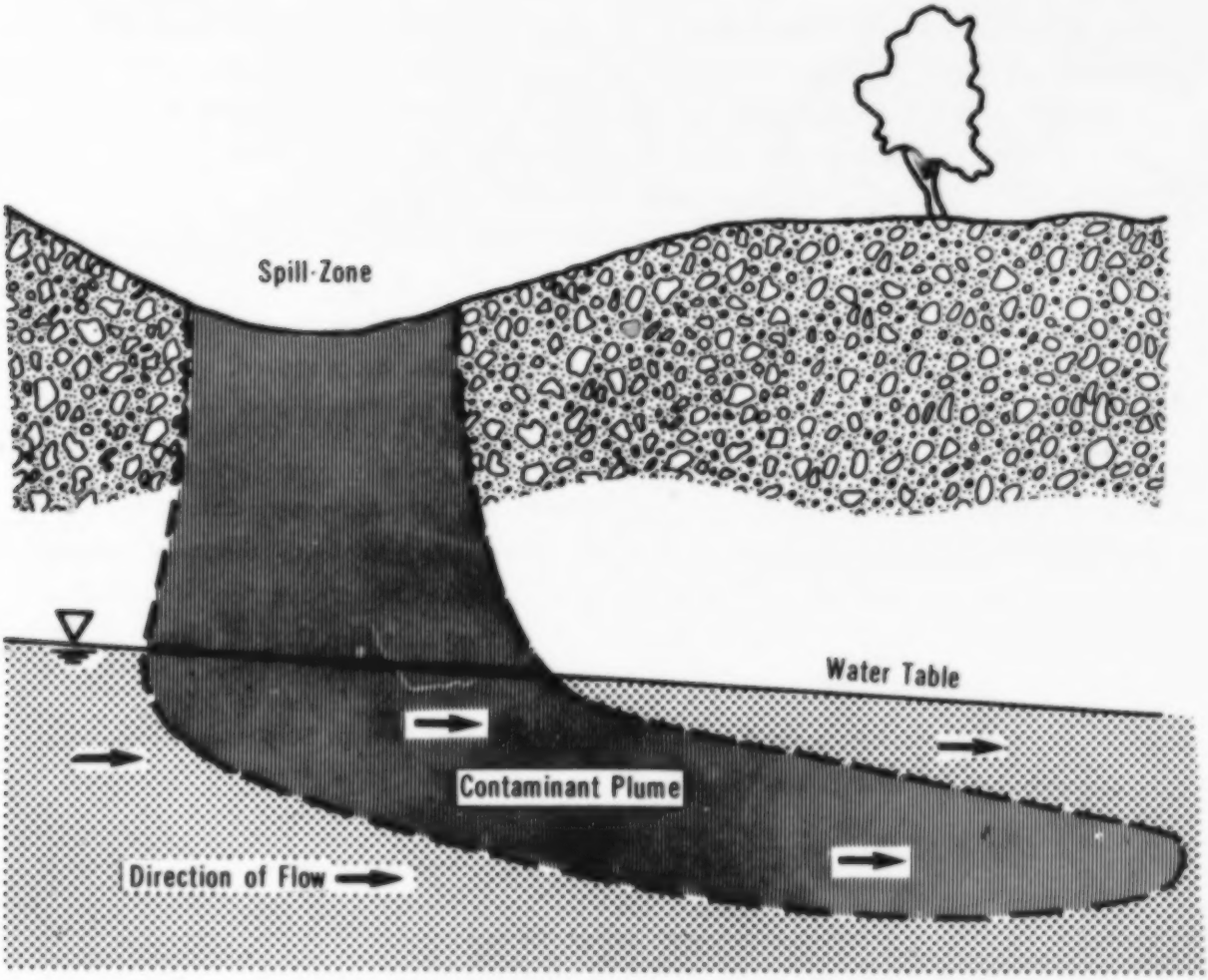
where:
- k = intrinsic permeability of the soil (m^2)
- ρ = mass density of the fluid (kg/m^3)
- μ = absolute viscosity of the fluid (Pa·s)
- g = acceleration due to gravity = 9.81 m/s^2

Because of the manner in which the solution is created (i.e., precipitation falling on spilled solid) it is assumed that it has fluid properties similar to those of water:

FIGURE 13

SODIUM SULPHATE

SCHEMATIC SOIL TRANSPORT



Soil: Coarse Sand

–Porosity (n) = 0.35

–Intrinsic Permeability (k) = 10^{-9} m^2

–Field Capacity (θ_{fc}) = 0.075

Property	Dilute Solution (4°C)	Water (20°C)
Mass density (ρ), kg/m^3	1000	998
Absolute viscosity (μ), Pa-s	1.57×10^{-3}	1.0×10^{-3}
Saturated hydraulic conductivity (K_o), m/s	$(0.62 \times 10^{7})k$	$(0.98 \times 10^{7})k$

5.5.4 Soils. The Introduction Manual describes the three soils selected for this work. Their relevant properties are:

Property	Soil Type		
	Coarse Sand	Silty Sand	Clay Till
Porosity (n), m^3/m^3	0.35	0.45	0.55
Intrinsic permeability (k), m^2	10^{-9}	10^{-12}	10^{-15}
Field capacity (θ_{fc}), m^3/m^3	0.075	0.3	0.45

5.5.5 Penetration Nomograms. Nomograms for the penetration of dissolved sodium sulphate into the unsaturated zone above the groundwater table were prepared for each soil. They present penetration time (t_p) plotted against depth of penetration (B). Because of the methods and assumptions used, the penetration depth should be considered as a maximum depth in time t_p. A flowchart for the use of nomograms is presented in Figure 14. The nomograms are presented as Figures 15, 16 and 17.

5.5.6 Sample Calculation. A 20-tonne spill of sodium sulphate has occurred on a silty sand soil. The radius of the spill is 8.6 m and the temperature is 20°C. Rain begins prior to cleanup. Calculate the depth of contaminant penetration 4 days after commencement of the rainfall.

Solution

Step 1: Define parameters

- Mass spilled = 20 000 kg (20 tonnes)
- T = 20°C
- Soil = silty sand

FIGURE 14

SODIUM SULPHATE

FLOWCHART FOR NOMOGRAM USE

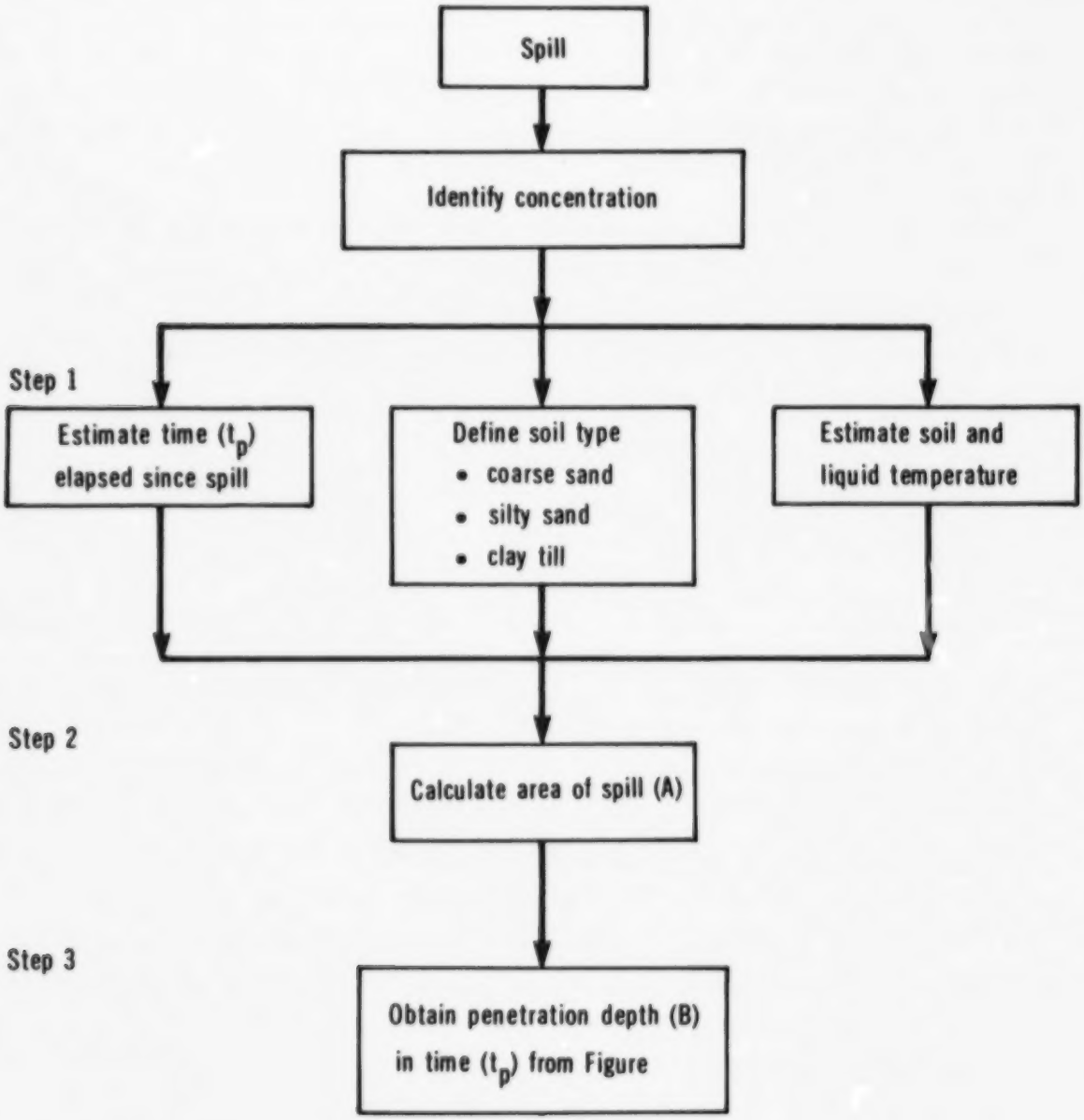


FIGURE 15

SODIUM SULPHATE

PENETRATION IN COARSE SAND

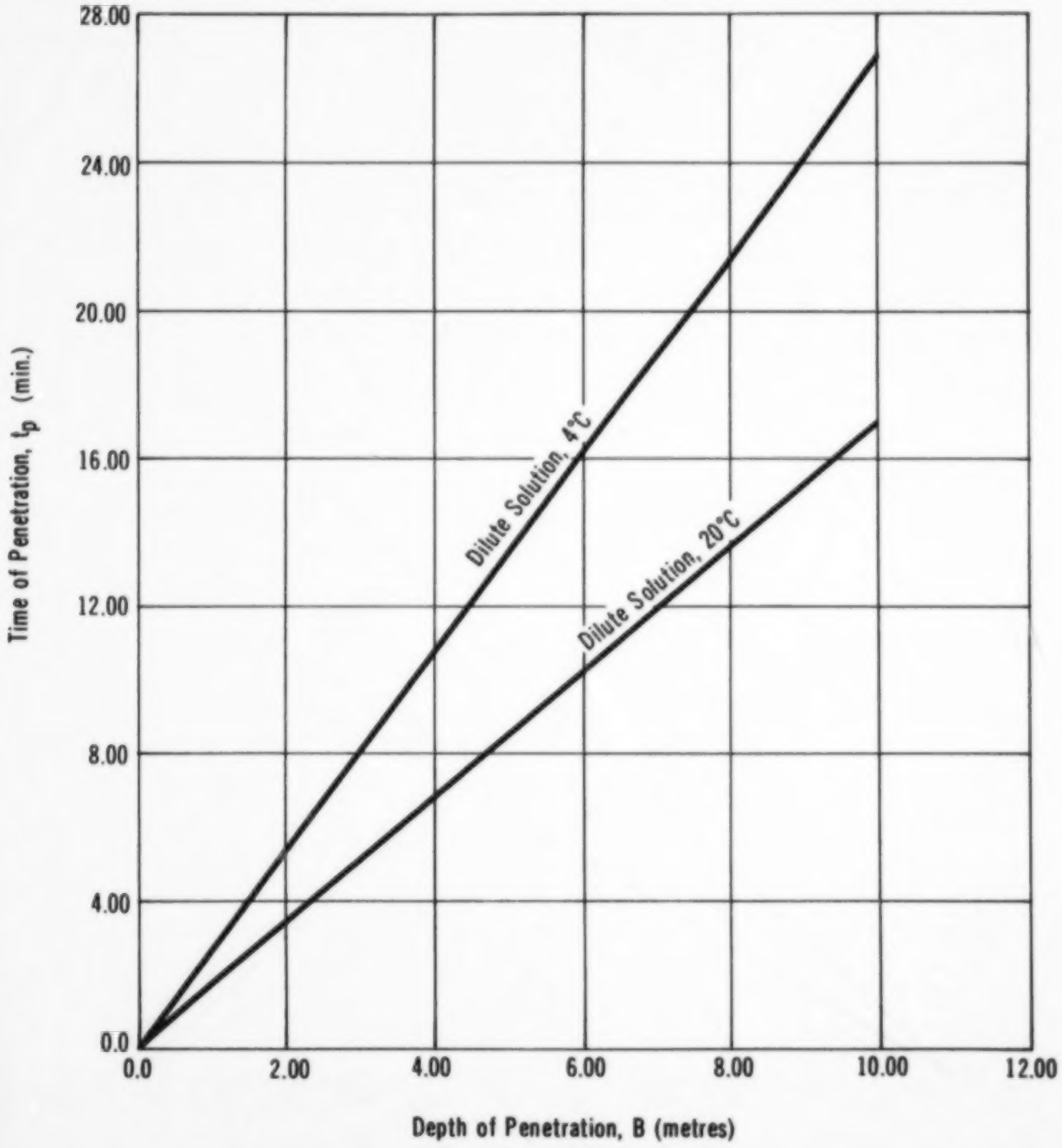


FIGURE 16

SODIUM SULPHATE

PENETRATION IN SILTY SAND

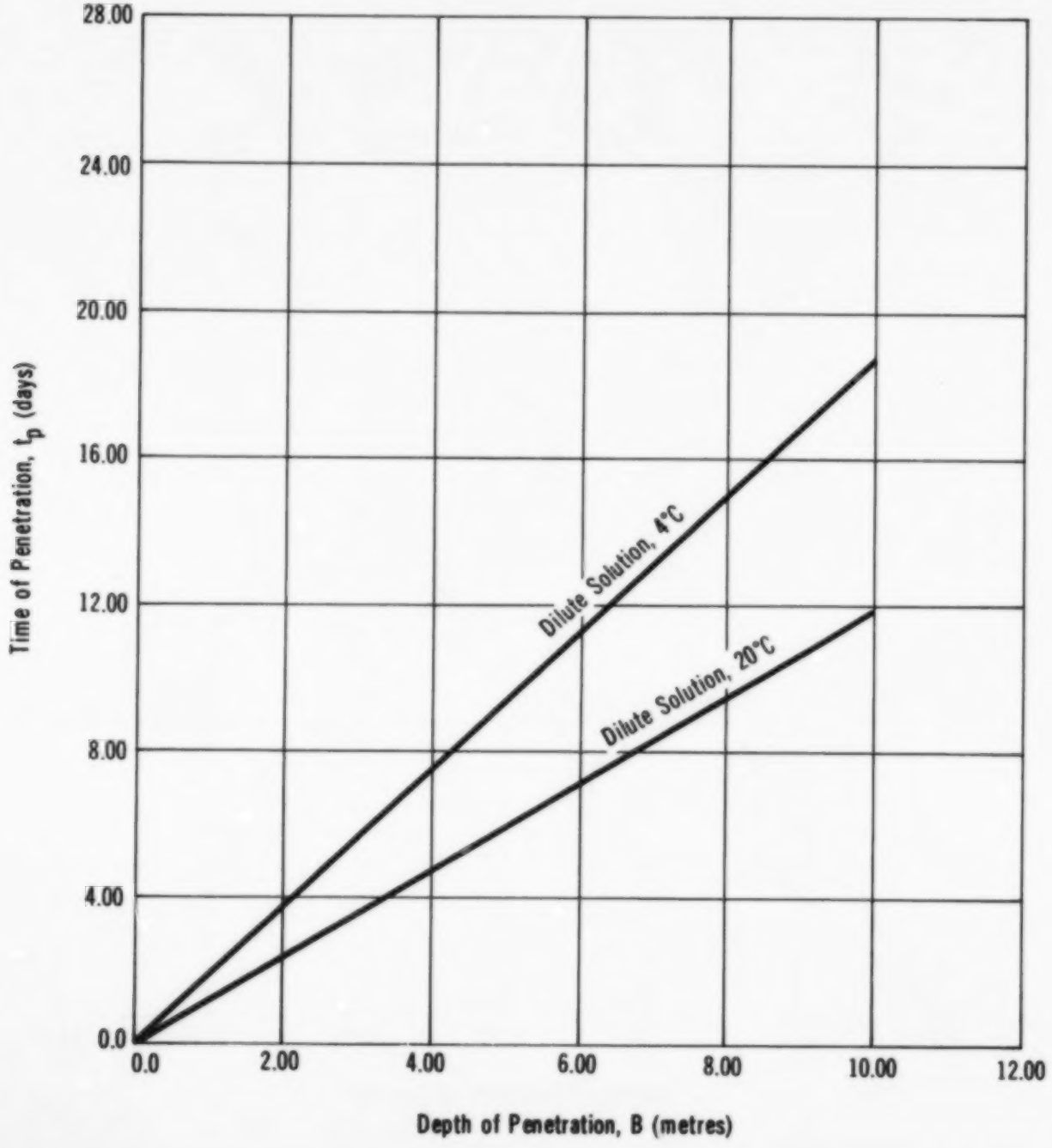
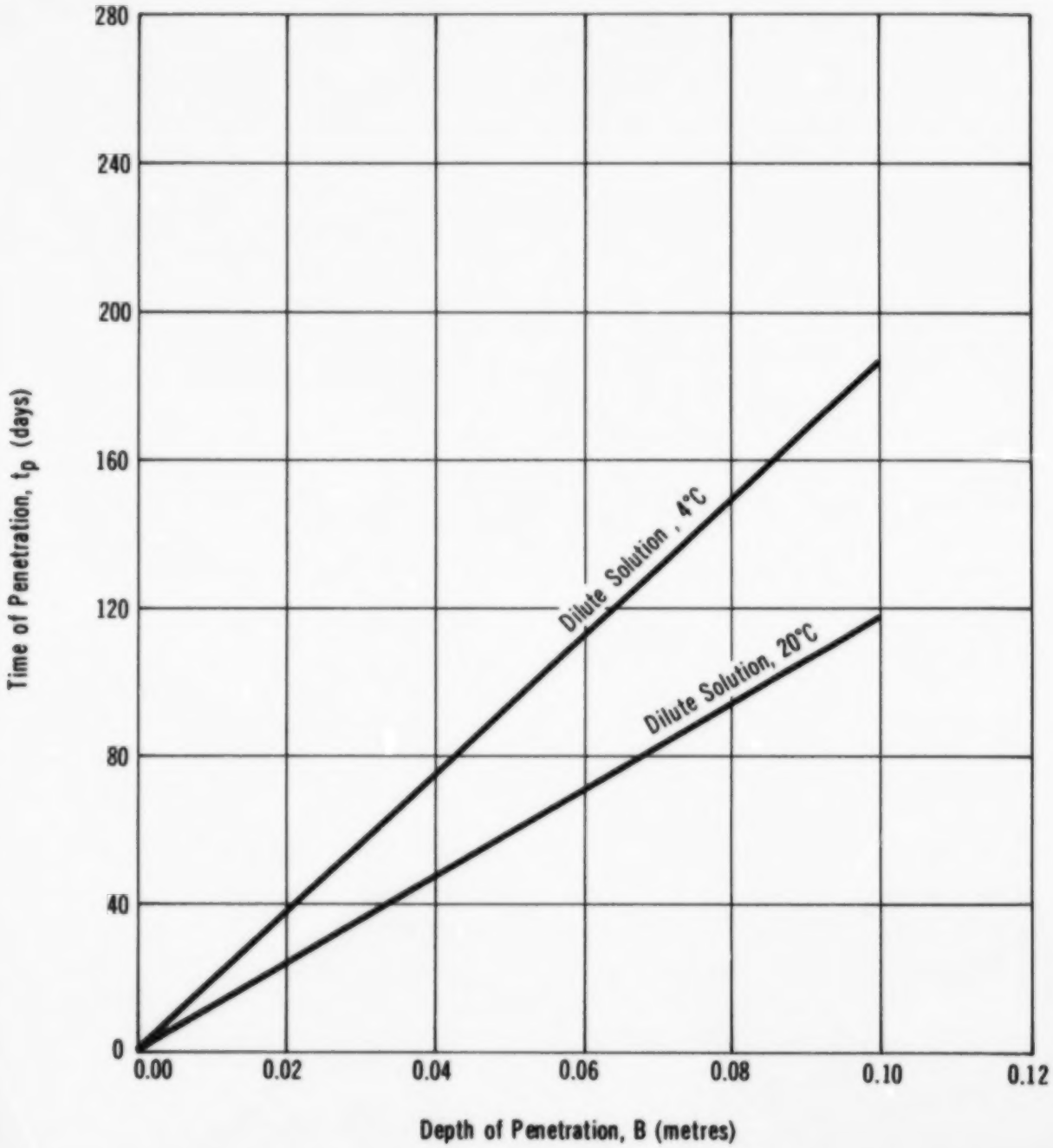


FIGURE 17

SODIUM SULPHATE

PENETRATION IN CLAY TILL



- Groundwater table depth (d) = 13 m
- Time since spill (t_p) = 4 days

Step 2: Estimate the depth of penetration (B) at time (t_p)

- For silty sand and t_p = 4 days, the depth of penetration is 3.4 m
- The spill has not reached groundwater in this time

6 ENVIRONMENTAL DATA

6.1 Suggested or Regulated Limits

6.1.1 Water. Sodium sulphate concentration in drinking water is not specifically regulated; however, health authorities should be notified when the sodium concentration exceeds 20 mg/L. For sulphate, the objective concentration is less than 150 mg/L, based on the taste threshold for sodium sulphate. The maximum acceptable is 500 mg/L (Guidelines/Canadian/Water 1978).

Ontario recommends that sulphate concentrations not exceed 250 mg/L (Water Management Goals 1978). This limit is the same as the 1961 WHO European Standard (WQCDB-2 1971).

6.1.2 Air. Not specifically regulated.

6.2 Aquatic Toxicity

6.2.1 Measured Toxicities.

Conc. (mg/L)	Time (hours)	Species	Result	Water Conditions	Reference
Fish Toxicity Tests					
13 500	96	Bluegill	LC_{50}	static	WQCDB-5 1973
12 500	96	Bluegill	LC_{50}	aerated	WQCDB-2 1971
100	120	Shiners	toxic		WQC 1963
17 500	48	Mosquito fish	LC_{50}	turbid water	WQCDB-2 1971
9000 to 13 000	24 to 96	Fathead minnow	LC_{50}	soft water	WQCDB-2 1971
13 500 to 14 000	24 to 96	Fathead minnow	LC_{50}	hard water	WQCDB-2 1971
5000	24 to 120	Fingerling trout	toxic		WQC 1963
7000	24 to 48	Rainbow trout	toxic		WQC 1963
16 500	-	Silver salmon	toxic		WQC 1963
16 700	6	Minnows	toxic	hard water	WQC 1963

Conc. (mg/L)	Time (hours)	Species	Result	Water Conditions	Reference
16 500	120	Coho salmon	minimum fatal concentration		WQCDB-2 1971
6700	120	Cutthroat trout	minimum fatal concentration		WQCDB-2 1971
Microorganisms					
10 000		*Fragilaria*	no growth		Stalbb 1973
30 000		*Scenedesmus chlamydomonas*	no growth		Stalbb 1973
1900		*Nitzschia linearis*	LC_{50}	static	WQCDB-5 1973
1000		Hydra	toxic		WQC 1963
6800	24	*Daphnia magna*	LC_{50}		WQCDB-2 1971
4547	96	*Daphnia magna*	LC_{50}		WQCDB-2 1971
7105	0	*Daphnia magna*	toxicity threshold	Lake Erie water	WQCDB-2 1971
5960	0	*Daphnia magna*	immobilization threshold	Lake Erie water	WQCDB-2 1971
2752		*Daphnia magna*	toxicity threshold	1.46 mg/L dissolved O_2	WQC 1963
5514		*Daphnia magna*	toxicity threshold	6.6 mg/L dissolved O_2	WQC 1963
Invertebrates					
35 600		Water beetles	stimulate movement		WQC 1963
320	960	Caddis fly (Stenonema ares)	LC_{50}	soft water	WQCDB-2 1971
5000	68	Water snails	toxic		WQC 1963
5000	24 to 144	Microcrustacea	toxic		WQC 1963
6820		*Polycelis nigra*	toxic		WQC 1963
2380	24	various amphipods	LC_{50}	lake water	WQCDB-2 1971

Conc. (mg/L)	Time (hours)	Species	Result	Water Conditions	Reference
1110	48	Various amphipods	LC_{50}	lake water	WQCDB-2 1971

6.3 Mammalian Toxicity

Water with sulphate concentrations above 500 mg/L may result in gastrointestinal irritation (Water Quality Sourcebook 1979). Sulphate levels of 7000 mg/L resulted in weight loss in cattle; rats were not harmed by 15 000 mg/L (WQC 1963).

6.4 Other Land and Air Toxicity

Poultry mortality was 33 percent after drinking water containing 7500 mg/L sodium sulphate for 15 days (WQC 1963). Plants were injured by sodium sulphate levels of 4000 mg/L in soil; 710 mg/L depressed root growth and water absorption. Crop weight reductions ranging up to 85 percent have been demonstrated for rice, tomato and beans with sodium sulphate levels up to 5120 mg/L (WQC 1963).

A study on soil changes with sodium sulphate showed that dilute solutions (0.1 and 0.01 N) penetrated at rates similar to that of water. The soil aggregation changed significantly in the top 10 cm as compared to water, but at depths greater than 10 cm was similar to water. The study also showed that a large amount of calcium was leached downward (Cairns 1973).

6.5 Long-term Fate and Effects

Sodium sulphate may persist indefinitely in the environment. It does not show bioaccumulation or food chain contamination effects (OHM-TADS 1981).

7 HUMAN HEALTH

There is very little information on the human toxicity of sodium sulphate in the published literature; no exposure standards were found. Sodium sulphate is considered nontoxic and nonirritating to the skin and mucous membranes (Lefèvre 1980). It acts as a laxative and has consequently been used as a first aid measure to accelerate the elimination of toxic products from the intestine.

No information was found concerning the chemical's potential as a mutagen, teratogen or carcinogen. The compound is reported in the EPA TSCA Inventory. The toxicological data summarized here have been extracted from reliable standard reference sources and are representative of information in the literature.

7.1 Recommended Exposure Limits

No exposure standards for sodium sulphate were found in the literature.

7.2 Irritation Data

7.2.1 Skin Contact.

Exposure Level (and Duration)	Effects	Reference
SPECIES: Unspecified		
40 percent suspension in mineral oil	No effect.	Koppers PD 1981

7.2.2 Eye Contact.

Exposure Level (and Duration)	Effects	Reference
SPECIES: Unspecified		
40 percent suspension in mineral oil	No effect.	Koppers PD 1981
40 mg/eye	Powder instilled in eye. No effects.	Koppers PD 1981

7.3 Threshold Perception Properties

7.3.1 Odour. Odour Characteristics: Odourless.

7.3.1 Taste.

Parameter	Media	Concentration	Reference
Lower Taste Threshold	Water	250 ppm	OHM-TADS 1981
Upper Taste Threshold	Water	500 ppm	OHM-TADS 1981

7.4 Toxicity Studies

7.4.1 Inhalation.

Exposure Level (and Duration)	Effects	Reference
Acute Exposures		
SPECIES: Rat		
Unspecified concentration (6 h)	No effect.	Koppers PD 1981

7.4.2 Ingestion.

Exposure Level (and Duration)	Effects	Reference
Acute Exposures		
SPECIES: Human		
500 mg/L	In drinking water with 1200 mg/L of magnesium sulphate, occasionally has caused diarrhea among human beings.	OHM-TADS 1981
SPECIES: Livestock		
2050 mg/L	Threshold limit in water.	OHM-TADS 1981
SPECIES: Rat		
7.07 g/kg	LD_{50}	Koppers PD 1981

Exposure Level (and Duration)	Effects	Reference
SPECIES: Mouse		
5989 mg/kg	LD_{50}	RTECS 1979

7.4.3 Percutaneous.

Exposure Level (and Duration)	Effects	Reference
SPECIES: Rabbit		
>4.0 g/kg	LD_{50}	Koppers PD 1981

7.4.4 Intravenous.

Exposure Level (and Duration)	Effects	Reference
SPECIES: Rabbit		
4470 mg/kg	LD_{LO}	RTECS 1979
SPECIES: Mouse		
1220 mg/kg	LD_{LO}	RTECS 1979

7.4.5 Mutagenicity, Teratogenicity and Carcinogenicity. No data.

7.5 Symptoms of Exposure

General symptoms of exposure found in most information sources have not been specifically referenced. Only those of a more specific or unusual nature have their sources indicated.

7.5.1 Inhalation. No data.

7.5.2 Ingestion.

1. Discomfort.

2. Stomach pains.

7.5.3 Skin. Considered nontoxic and nonirritating to skin and mucous membranes (Lefèvre 1980).

7.5.4 Eye Contact.

1. Mechanical irritation (Lefèvre 1980).
2. Watering of eyes (Lefèvre 1980).

8 CHEMICAL COMPATIBILITY

8.1 Compatibility of Sodium Sulphate with Other Chemicals and Chemical Groups

SPECIFIC CHEMICAL OR CHEMICAL GROUP	HEAT GENERATION	FIRE	EXPLOSION	FORMATION OF FLAMMABLE GASES	VIOLENT POLYMERIZATION	DECOMPOSITION	FORMATION OF TOXIC FUMES	FORMATION OF SUBSTANCES OF GREATER TOXICITY	PRESSURIZATION IN CLOSED VESSELS	SOLUBILIZATION	VIOLENT REACTION	NON-HAZARDOUS REACTION	SPECIFICS	REFERENCE
GENERAL														
Fire					•	•							Toxic fumes of sulphur oxides may be emitted.	Sax 1979
Heat					•	•							Toxic fumes of sulphur oxides may be emitted.	Sax 1979
SPECIFIC CHEMICALS														
Aluminum		•											At a temperature of 800°C.	Bretherick 1979
Magnesium										•				Sax 1979

9 COUNTERMEASURES

9.1 Recommended Handling Procedures

The following procedures have been derived from a literature review. To avoid any deviation from the intended meaning, the wording of the original source has been presented essentially unchanged - in so doing, it is recognized that there may be discrepancies between different sources of information. It is recognized that countermeasures are dependent on the situation, and thus what may appear to be conflicting information may in fact be correct for different situations. The following procedures should not be considered as Environment Canada's recommendations.

9.1.1 Fire Concerns. Sodium sulphate is a noncombustible solid (ERM 1982).

9.1.2 Fire Extinguishing Agents. Most fire extinguishing agents may be used in fires involving sodium sulphate (ERM 1982).

9.1.3 Spill Actions, Cleanup and Treatment.

9.1.3.1 General. Stop or reduce discharge of material if this can be done without risk.

9.1.3.2 Spills on land. Contain if possible by forming mechanical barriers to prevent spreading (EPA 670/2-75-042). Shovel material into containers for recovery or disposal.

9.1.4 Disposal. Waste sodium sulphate must never be discharged directly into sewers or surface waters. With environmental authorities, approval, recovered sodium sulphate may be disposed of by burial in a landfill.

9.1.5 Protective Measures. For entry into a situation where the spilled material and its characteristics are unknown, self-contained breathing apparatus and a totally encapsulated chemical suit should be worn.

If the spilled material is known to be sodium sulphate:

- Tight-fitting safety goggles, rubber gloves and protective clothing should be worn (ERM 1982).

10 PREVIOUS SPILL EXPERIENCE

This section contains information on previous spill experience which will be useful to readers in understanding spill response and countermeasures. Only those which meet the criteria are included, and thus, the number of experiences is not an indication of the problems or frequency of spillage. As technology in spill control advances, this section will be updated in future manual revisions to include the most useful information.

11 ANALYTICAL METHODS

The general approach adopted for each of the Priority Chemicals was as follows.

Methods have been documented here for the analysis of samples from air, water and soil in a normally equipped chemical laboratory remote from the spill site. Customary sources of standard or recommended analytical methods were consulted, and outlines are presented for each chemical. These sources included publications of the U.S. National Institute for Occupational Safety and Health (NIOSH), the U.S. Environmental Protection Agency (EPA), the American Water Works Association (AWWA), the American Society for Testing and Materials (ASTM), and the American National Standards Institute (ANSI).

If the standard or recommended methods were judged to be reliable and specific enough for the analysis of environmental and materials samples from spill sites and if they do not require highly specialized laboratory equipment, no additional methods were sought. If especially simple, reliable tests (e.g., commonly used industrial methods) were found, they have been presented as well.

11.1 Quantitative Method for the Detection of Sodium Sulphate in Water

11.1.1 Flame Photometry (ASTM 1979). Concentrations greater than 1 mg/L (ppm) of sodium sulphate as sodium may be determined by flame photometry. A minimum volume of 2 L of representative sample is collected in an appropriate container. A suitable volume of sample is atomized into the flame of a suitable flame photometer and the emission intensity determined at 589 nm. The sample concentration is determined using a calibration curve.

11.2 Quantitative Method for the Detection of Sodium Sulphate in Soil

11.2.1 Flame Photometry (Hess 1972). A variable range of concentrations of sodium sulphate as sodium in soil may be determined depending on the aliquot of extract atomized into a suitable flame photometer.

A 5 g sample of 2 mm (sieve-size) soil, accurately weighed, is placed in a 50 mL narrow neck centrifuge tube. A 30 mL volume of 0.5 M magnesium acetate solution is added, the tube stoppered, and centrifuged for 5 minutes at 400 rev/s.

The supernatant is decanted into a 100 mL volumetric flask. The extraction is repeated twice more and the extracts combined in the volumetric flask. The combined

extracts are diluted to volume with 0.5 M magnesium acetate. A suitable aliquot of sample is atomized into the flame of a suitable flame photometer and the emission intensity determined at 589 nm. The sample concentration is determined using a calibration curve.

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EnviroTIPS

Common Abbreviations

BOD	biological oxygen demand
b.p.	boiling point
CC	closed cup
cm	centimetre
CMD	count median diameter
COD	chemical oxygen demand
conc	concentration
c.t.	critical temperature
eV	electron volt
g	gram
ha	hectare
Hg	mercury
IDLH	immediately dangerous to life and health
Imp. gal.	imperial gallon
in.	inch
J	joule
kg	kilogram
kJ	kilojoule
km	kilometre
kPa	kilopascal
kt	kilotonne
L	litre
lb.	pound
LC_{50}	lethal concentration fifty
LC_{LO}	lethal concentration low
LD_{50}	lethal dose fifty
LD_{LO}	lethal dose low
LEL	lower explosive limit
LFL	lower flammability limit
m	metre
m	meta
M	molar
MAC	maximum acceptable concentration
max	maximum
mg	milligram
MIC	maximum immission concentration
min	minute or minimum
mm	millimetre
µg	microgram
µm	micrometre
°Be	degrees Baumé (density)
MMAD	mass median aerodynamic diameter
MMD	mass median diameter
m.p.	melting point
MW	molecular weight
N	newton
NAS	National Academy of Sciences
NFPA	National Fire Protection Association
NIOSH	National Institute for Occupational Safety and Health
nm	nanometre
o	ortho
OC	open cup
p	para
P_C	critical pressure
PEL	permissible exposure level
pH	measure of acidity/alkalinity
ppb	parts per billion
ppm	parts per million
P_S	standard pressure
psi	pounds per square inch
s	second
STEL	short-term exposure limit
STIL	short-term inhalation limit
T_C	critical temperature
TC_{LO}	toxic concentration low
Td	decomposition temperature
TD_{LO}	toxic dose low
TL_m	median tolerance limit
TLV	Threshold Limit Value
Ts	standard temperature
TWA	time weighted average
UEL	upper explosive limit
UFL	upper flammability limit
VMD	volume mean diameter
v/v	volume per volume
w/w	weight per weight